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STUDY OF POTENTIAL FOR MOTOR VEHICLE FUEL ECONOMY IMPROVEMENT

FUEL ECONOMY TEST PROCEDURES PANEL REPORT NO. 6

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16. Abstract

This Fuel Economy and Test Procedures Panel Report is No. 6 of a group of seven (7) prepared by special panels of the Task Force established under the joint chairmanship of DOT and EPA to conduct a study of the practicability of a fuel economy improvement standard of 20% for new motor vehicles produced in the 1980 time frame.

This report presents the test procedures recommended for insuring compliance with fuel economy regulations. Discussions included are: (a) driving variables pertinent to the establishment of a meaningful, reproducible test methodology; (b) test and measurement methods which are applicable to fuel economy certification tests; (c) current test procedures in use by industry and the federal government, and (d) recommendations for a standardized Federal Test Procedure.

The recommendation is that federally conducted fuel economy tests for labeling and/or certification be performed on a chassis dynamometer using two driving schedules - city and highway.

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PREFACE

This Fuel Economy and Test Procedures Panel Report is No. 6 of a group of seven (7) prepared by special panels of the Task Force established under the joint chairmanship of DOT and EPA to conduct a study of the practicability of a fuel economy improvement standard of 20% for new motor vehicles produced in the 1980 time frame. Each panel addressed a major impact area and drew on a variety of sources in preparing its report, including previous DOT and EPA research, and industry and public comments.

Materials developed by the various study panels were used in preparing the Report to Congress entitled "Potential for Motor Vehicle Fuel Economy Improvement", dated 24 October 1974 (second printing, 18 November 1974). Assumptions and conclusions expressed in the panel reports, however, are those of the respective panels and do not necessarily reflect official positions or policies of the U.S. Department of Transportation, the U.S. Environmental Protection Agency, or the study Task Force.

The complete Panel Reports set consists of the following:

Report No. 1: Policy Assessment Panel Report
Report No. 2: Safety Implications Panel Report
Report No. 3: Air Quality and Emissions Panel Report
Report No. 4: Technology Panel Report
Report No. 5: Economics Panel Report
Report No. 6: Fuel Economy Test Procedures Panel Report
Report No. 7: Truck and Bus Panel Report

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1. INTRODUCTION

This Fuel Economy Test Procedures Panel report of the joint U.S. Environmental Protection Agency (EPA) - U.S. Department of Transportation (DOT) 120 - Day Fuel Economy Study is one of seven panel reports submitted to the Study Task Force: Mr. Eric Stork, EPA; Dr. R. E. Goodson, DOT; and the representatives of the Treasury Department, The Federal Energy Agency and the Council on Environmental Quality.

In order to facilitate the establishment of a standardized Federal fuel economy test procedure it is necessary to specifically define the critical variables. The variables which affect fuel economy generally can be grouped into three categories: (a) Driving variables; including the route over which the driving takes place, the ambient and road conditions, and trip conditions such as trip length, cold or hot start, etc.; (b) Vehicle variables; such as basic configuration (engine, weight, drive train, body style, tires), break-in mileage and state of tune; and (c) Driver habits; such as rate of acceleration from a stop and ability to maintain a constant speed while cruising.

In designing a standardized, reproducible fuel economy test, it becomes immediately apparent that the test cannot account for differences between drivers (i.e., driver habit variables). The application of appropriate vehicle sampling techniques insure that the test fleet adequately represents the critical vehicle variables. The test procedure, therefore, is directed primarily toward accurate simulation of the driver variables.

The primary goal for a fuel economy test procedure is the generation of a fuel economy value for a specific vehicle configuration which will adequately represent typical vehicle operation. The driving schedules and test conditions should be designed to accurately simulate the critical driving variables; the test and measurement methodology should be designed for maximum reproducibility and accuracy. Driver habits can not

be accounted for as part of the test due to the difficulty in defining "average driving" and to the wide fuel economy range possible.

The subsequent sections of this report are directed toward detailed discussions of driving variables, test and measurement methods and current test procedures and conclusions regarding a standardized fuel economy test procedure.

2. SUMMARY AND CONCLUSIONS

This section presents the test procedures recommended for insuring compliance with fuel economy regulations. Discussions included are: (a) driving variables pertinent to the establishment of a meaningful, reproducible test methodology; (b) test and measurement methods which are applicable to fuel economy certification tests; (c) current test procedures in use by industry and the federal government, and (d) recommendations for a standardized Federal Test Procedure.

There are currently two "standard" test procedures being used to measure fuel economy. EPA has developed a dynamometer procedure which measures fuel economy for two types of driving: city and highway; the city test is also used to determine compliance with Federal emissions standards. These tests allow the fuel consumed to be measured directly from the emissions data, or by weight or volume. The SAE has recently completed a track procedure which determines fuel economy for three types of driving: urban, suburban and interstate. Fuel consumption is measured directly either by weight or volume. The SAE is also preparing a dynamometer procedure; however, though a proposed version is described in this document, it is not yet available for final evaluation. Both the EPA and SAE procedures if conducted properly, can be used to determine automotive fuel economy. However, both of the procedures have specific limitations which restrict their range of applicability.

2.1 STANDARD FUEL ECONOMY TEST PROCEDURES

Based on a careful assessment of all available information regarding fuel economy test procedures, it is recommended that federally conducted fuel economy tests for labeling and/or certification be performed on a chassis dynamometer using two driving schedules - one corresponding to city travel and one to highway travel. The test procedure should be based on current EPA procedures with refinements in the areas of road load

simulation and distance measurement. Since it is likely each vehicle tested for fuel economy must also be certified for emissions, a combined test based on the 1975 Federal Test Procedure with an appropriately weighted cold start would be appropriate for the "city" portion of the test. The fuel economy value should be calculated from a weighted average of the fuel consumed during the city and highway driving schedules in accordance with the vehicle miles travelled (VMT) in each driving category (55% - city, 45% - highway).

It should be recognized that a dynamometer test is a simulation of an actual road test and thus must be carefully designed to insure that all factors critical to fuel consumption are properly considered. Aerodynamic drag and tire rolling resistance are two specific areas which enter strongly into the trade off between test accuracy and test sophistication (i.e., cost). The primary advantages of dynamometer testing are: that it is not sensitive to adverse weather conditions; the test conditions can be more carefully controlled; a more realistic driving schedule can be used; and emissions can be tested concurrently.

Track tests, such as recommended by the SAE, obviously allow a test of a vehicle under actual operating conditions; however, the test accuracy may be affected by the track conditions, driving schedule, driver habits and test instrumentation. The combined effects of these factors can serve to reduce the overall accuracy to a level commensurate with a moderately sophisticated dynamometer procedure. In addition, the strict limits on weather conditions and track design required for a repeatable track test will impact the logistical aspects of testing a large number of vehicles. Finally, a federally conducted fuel economy test program would require rental or construction of a special test track. If a self-certification program were used, it would be feasible to use a track procedure since the manufacturers have test tracks available. However, the questions of track-to-track differences would have to be carefully considered before such a decision could be reached.

2.2 TEST VARIABILITY

The precision to which a fuel economy measurement can be made is a function of test variability (reproducibility of a test made on a single vehicle), and facility variability (differences between dynamometer or tracks). The current state-of-the-art in fuel economy measurements yields a possible test variability of ±2-4% for the same car on the same test facility. However, facility differences may increase the total measurement variability to ±3-6%. It is possible to reduce the overall variability by using more sophisticated test procedures and dynamometers, however the rationale for doing so should be carefully weighted against the anticipated increase in test costs. Also the basic vehicle-to-vehicle variability may prove to be the limiting factor in achieving an accurate fuel economy measurement in a practical fuel economy test program. This variability can be reduced only by increasing the number of vehicles tested.

2.3 DRIVING CYCLES

Two driving cycles should be used during the compliance test, one representing city driving and one representing highway driving. The current EPA cycles are recommended; however, periodic studies should be performed to monitor nationwide driving patterns and identify and changes which should be reflected in the schedules.

2.4 FUEL CONSUMPTION MEASUREMENT

Fuel consumed during the test may be measured with any of the following techniques: carbon-balance, volumetric or gravimetric. (Note: specifications for each technique will be tightened over current practice). Each technique, if used properly, can be expected to exhibit variabilities less than ±2%.

2.5 VEHICLE SELECTION

The vehicles comprising the compliance test fleet should be selected according to projected sales. The sampled vehicles

should include those configurations of weight, engine, drive train and aerodynamic load factors that may be expected to have a significant impact on fuel economy.

2.6 BASELINE FUEL ECONOMY CALCULATIONS

The fuel economy values used in other sections of this report were based on a combination of the EPA 1975 Federal Test Procedures (city) and the EPA Highway Driving Cycles (highway). The overall fuel economy (mpg) was calculated from the FTP and HDC fuel economy values in accordance with the vehicle-miles travelled in each driving category (55% - city, 45% - highway).

2.7 NECESSARY ADDITIONAL WORK

- Evaluate the SAE Dynamometer procedures (when available in final form) for possible adaptation into the Federal Standard Test Procedure.
- Develop a better understanding of tire behavior on dynamometer rolls.
- Determine the necessity for decreasing the inertia weight increment or extrapolating weight to increase test accuracy.
- Develop a procedure to incorporate true vehicle road load to an acceptable accuracy in dynamometer testing.
- Evaluate the possibility of simplified test procedures for use in statistically-based production-line testing or in-use inspections, should such be required by law. Note: this test procedure must be correlatable to the certification procedure, however, it may not have the same overall variability.
- Verify the correlation of the FTP and HDC to nationwide driving characteristics and establish the degree of representativeness.
- Develop a procedure to match track and dynamometer test results.
- Evaluate the effect of frigid and cold starts on fuel economy.

3. DISCUSSION OF DRIVING VARIABLES

3.1 THE DRIVING CYCLE; CHARACTERISTICS PERTINENT TO DRIVING CYCLE CHOICE

3.1.1 Relation to Actual Vehicle Operation

To fulfill its prime objective, to provide factual consumer information, a fuel economy measurement procedure must relate to real life conditions. The vehicles must be typical of those which are or will be produced, the vehicle must be operated in a typical manner, and the vehicle environment must be typical, in order for test results to be meaningful. Unfortunately, all of the important vehicle use characteristics show large real life variations, which result in large real life variations in fuel economy. During fuel economy testing, these characteristics must be controlled to standard or average values.

The primary vehicle use characteristics, which is highly variable in real life and which has a strong influence upon fuel economy, is the trip the vehicle takes. The trip is so dependent upon random fluctuations in such a wide variety of parameters (traffic, weather, road, etc.) that it can safely be said that in the real world no two trips are exactly the same. While it is possible to set vehicle and ambient characteristics to some recognized standard conditions, standard trips do not exist. It is necessary, therefore, to identify typical or average trip characteristics and to identify or simulate an average trip.

Trips can generally be characterized according to type or character of road system traversed and according to the type or purpose of the trip. The Department of Transportation segregates road systems into either of two categories on the basis of principal area characteristics. The two categories are urban and rural (highway), which are differentiated because of functional differences in land use, road networks, and travel characteristics.[1] DOT experience indicates that this differentiation in characteristics occurs in places of 5,000 population. Rural (highway)

road networks are adequate if place populations are less than 5,000, and urban traffic networks are required if the place populations exceed 5,000. In order to characterize road types within either category the Department of Transportation has developed a "Functional Classification Concept" which classifies each highway, road, or street according to the principal service that it renders. This system of classification develops a hierarchy of route types. Lowest in the hierarchy are the local roads and streets, where trips begin and end. These trip ends are characterized by low speeds, unlimited access, and penetration of neighborhoods. At the top of the hierarchy are the arterials designed to accommodate high volumes of through traffic. Intermediate facilities or collectors accommodate the necessary transition from local roads and streets to arterials. Thus, vehicles can be said to operate in either an urban or a rural environment. Urban operation represents between 50 and 60% of total vehicle miles travelled[1] (55% urban, 45% rural is a division commonly used), a value which continually increases as urbanization increases. It is possible to construct a trip which consists of 55% urban travel and 45% rural travel and derive only one fuel economy number from the combined trip. If separate urban and rural trips are constructed, urban, rural, and combined fuel economies can be reported. Changes in the split between urban and rural travel can be accommodated simply by a change in weighting factors. The driving schedules need not be changed.

The trips, road routes, or driving schedules must be representative of their respective types of travel, urban or rural. Therefore, urban and rural travel must be characterized according to those parameters which are important to fuel economy. Such characterization can be a difficult and time consuming, expensive process. Such a characterization may result in the development of an actual, typical road route[2] or may provide sufficient data that routes may be synthesized or simulated.[3] Obviously, when a road route is simulated and does not actually exist, some mechanism for exercising the vehicle must be found. Not so obvious is that the same is true even when a road route exists. Road routes are, of necessity, in the public domain and are subject to

change as a result of changing public use requirements.[4] In order to maintain the appropriate driving characteristics, it is necessary to record and/or store the operating characteristics so that the vehicle can be exercised in a controlled test area such as a test track or on a chassis dynamometer. Many methods for recording and storing such information have been tried.[2,4,5] The most direct method for transferring the route characteristics to a controlled test area is to gather speed versus time data for a typical vehicle drive over the route and transfer these data to a speed versus time driving chart which is to be followed on the track or chassis dynamometer. This method preserves all of the minor speed changes which actually occur in real life driving.

When a typical route is not available or typical route segments cannot be identified, a vehicle operations survey will probably be required before an appropriate route can be constructed or a typical driving schedule can be synthesized.[6,7] If the data are gathered on a speed versus time basis in a computer compatable format, computer data analysis and subsequent synthesis of a simulated driving schedule are possible. Such a project requires utilization of skilled statisticians and computer technologists. Even so, the task of synthesizing a specific route from averaged driving characteristics is so difficult that in order for the task to be accomplished at all, simplifying assumptions must be made and data are lost in the consolidation or averaging process. As a result, the minor speed changes which characterize real driving are lost or significantly modified by the computer simulation. Any driving schedule generated by current computer techniques is not quite representative of real driving.

Another method sometimes used for transfer of road data to a controlled test area, is to identify the major traffic operating conditions and to combine these to form simple, straight line, repetitive driving cycles. This method was used in the early days of emission testing and resulted in a development of the 7-mode cycle.[8,9] The problem with such simple cycles is that only a few of the major modes can be included, and the cycles developed in this fashion bear only superficial relationships to real life

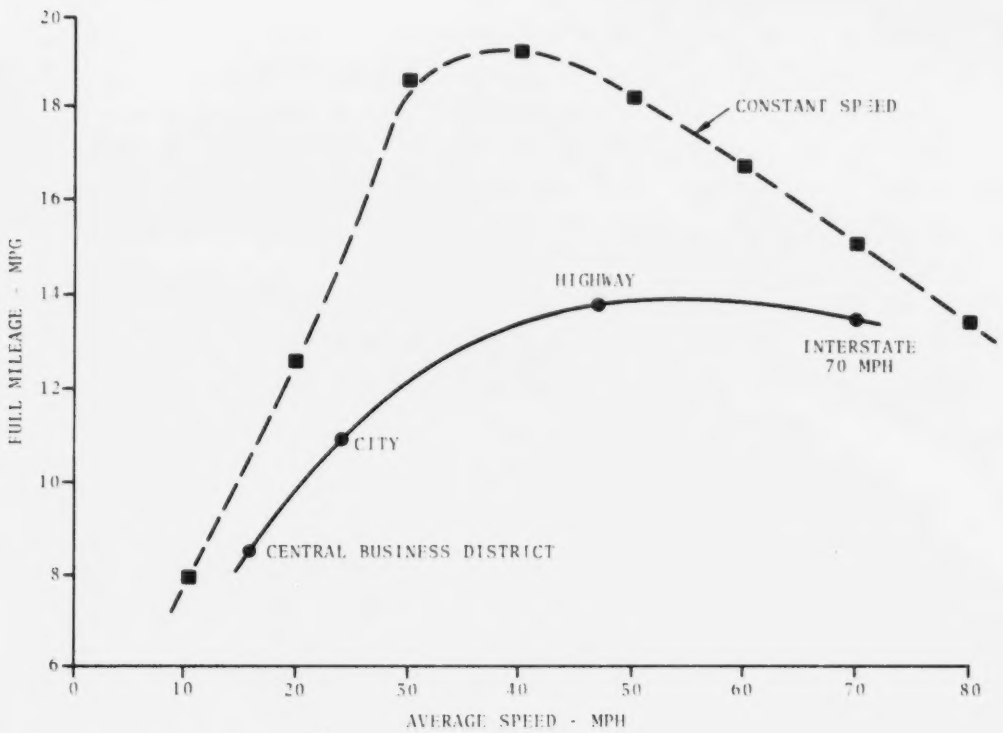
driving. These minor speed changes are an intimate part of real life driving and always show up when real driving data are taken. The minor modes which individually account for only small fractions of total driving time, are (must be) discarded in the development of simple cycles. Collectively, these minor modes account for a significant portion of vehicle operation. An example is the well known 7-mode cycle shown in Table 1. The chart is the Federal Register description of the cycle. Note that although 10 sequences are required for the complete cycle, only seven modes are read. In particular, note that data are not taken during the 30 to 50 acceleration. With this cycle, the vehicle decelerates from 50 to 20 without even (as far as the cycle is concerned) having accelerated from 30 to 50. Such compromises with reality are required for

TABLE 1 7-MODE DRIVING SCHEDULE

Sequence No.	Mode	Acceleration mph/sec.	Time in mode seconds	Cumulative time seconds	Weighting factor
1--------	Idle	---------	20	20	0.042
2--------	0-25	2.2	11.5	31.5	.244
			14	---------	---------
3--------	25-30		2.5	34	
4--------	30	---------	15	49	.118
5--------	30-15	-1.4	11	60	.062
6--------	15	---------	15	75	.050
7--------	15-30	1.2	12.5	87.5	.455
			29	---------	---------
8--------	30-50		16.5	104	
9--------	50-20	-1.2	25	129	0.029
10-------	20-0	-2.5	8	137	

Source: Federal Register, June 4, 1968 Vol. 33, Number 108 Pg. 8310

the development of any simple driving schedule. Even the relatively simple driving cycles currently used by the major automobile manufacturers for track testing were designed as simulations of real driving conditions.[4] Studies have been conducted to compare fuel economy from these cycles to fuel economy from steady mode testing. Figure 1 presents data for a 1972 GM Full Sized Car. Note that by these data there is even a difference in fuel economy (about 13%) between simulated interstate driving and steady 70 mph.



Source: GM Memorandum Report No. PG-34403, "Synopsis of Fuel Economy Meeting with Department of Commerce," Jack A. Arnold, Ronald A. Davis, William S. Freas, and Thomas M. Johnson.

Figure 1 Typical Fuel Economy Results - 1972 GM Full Sized Car

The data in Table 2 by Ford Motor Company and SAE are similar to those presented by GM in the preceding figure. The Ford data show less effect at interstate speeds. These data show that the Suburban fuel economy is 20% below the steady state 40 mph fuel economy and the I*-55 economy is 16% below the interpolated 55 mph fuel economy.

Table 3 presents data from another GM study. Note that the data from the 47 mph comparison show a fuel economy difference of 20% from steady state to simulated driving cycle. The 48 mph and the 53 mph data show much smaller differences (less than 5%) than do all of the other data presented here. This difference reflects a similarity in the basic characteristics of the high speed driving schedules. These data show the importance of simulating real life conditions, and these are relatively simple simulations. An even more realistic route simulation has been developed and is routinely used for Federal emission testing. The credability of the fuel economy test results will depend in large part upon the credability of the driving schedule. The more realistic the driving schedule, the more credible the results.

3.1.2 Descriptive Parameters

Several parameters which are descriptive of driving patterns have direct influences on fuel economy. The major parameters and their observed influences will be discussed. Driving schedules should be evaluated based, at least, upon consideration of each of the following parameters.

1. Average Speed

During normal vehicle operation, average speed is defined as the average of numerous instantaneous speeds, each set by prevailing conditions. Average speed is usually calculated by dividing the total accumulated distance by the elapsed time. In special circumstances, such as on test tracks or chassis dynamometers, vehicles can be operated at steady speeds. Fuel economy has been measured for different types of vehicles driven at steady speeds on level tracks and the results show that peak fuel economy is obtained at steady speeds of 35-45 mph (Figure 2).

TABLE 2 FUEL ECONOMY COMPARISON DATA

	FORD MOTOR CO.					SAE (J1082)			
	Fuel Economy (MPH)					15.6 MPH AVE.	41.1 MPH AVE.		
Vehicle	30 MPH	40 MPH	50 MPH	60 MPH	70 MPH	Urban	Suburban	I*-55	I-70
Sub Compact	26.8	24.3	22.7	20.7	17.9	15.1	19.6	20.7	17.2
Compact	21.1	21.8	22.3	20.3	17.4	12.1	18.2	20.4	17.4
Luxury	15.4	16.8	16.9	15.9	14.0	8.3	13.9	16.1	14.0

Source: Response of D.A. Jensen, Fort Motor Co., to a letter from Charles Gray, Jr., U.S. Environmental Protection Agency, P. 4

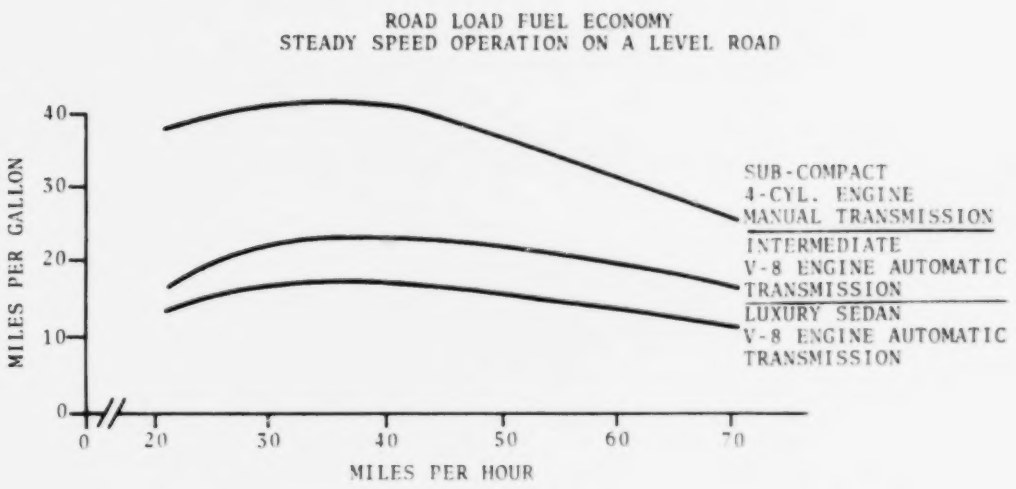
Source: "Fuel Economy Measurement - Road Test Procedure" - SAE J1082, SAE Recommended Practice - Approved April 1974.

TABLE 3. FUEL ECONOMY-MPG
1974 MODELS

	47 mph		48 mph		53 mph	
Sub-Compacts	Constant Speed	Highway	Constant Speed	Int.50	Constant Speed	Int.55
Car 1	27.9	22.8	27.7	26.8	26.9	25.7
Car 2	28.0	23.9	27.8	27.2	27.2	26.8
Compact-6						
Car 3	22.1	17.7	21.8	21.4	20.7	20.4
Car 4	22.0	17.7	21.8	21.1	20.6	20.3
Car 5	19.7	16.1	19.5	19.6	18.7	18.7
Compact-8						
Car 6	17.9	15.4	17.7	17.2	17.1	16.7
Car 7	18.1	15.6	18.1	18.2	17.7	17.6
Car 8	18.8	15.3	18.6	18.0	17.8	17.2
Car 9	19.4	15.5	19.3	18.9	18.8	18.0
Intermediate						
Car 10	16.2	14.1	16.2	16.0	15.8	15.4
Car 11	19.0	16.1	19.0	18.9	18.6	18.3
Car 12	18.4	15.2	18.3	17.7	17.8	16.9
Car 13	18.8	15.1	18.7	18.4	18.0	17.5
Car 14	16.2	14.0	16.2	16.0	16.0	15.4
Car 15	17.7	15.2	17.7	17.7	17.5	17.2
Full Size						
Car 16	16.3	13.9	16.2	15.7	15.5	15.3
Car 17	17.9	14.1	17.7	16.8	16.9	16.1
Car 18	17.4	13.6	17.4	16.8	17.0	15.9
Car 19	15.9	13.9	15.9	15.6	15.7	15.3
Car 20	18.9	15.5	18.8	18.5	18.3	17.8
Luxury						
Car 21	17.9	14.6	17.8	17.8	16.9	16.8
Car 22	17.7	13.7	17.6	16.3	16.8	15.7
Car 23	16.8	13.5	16.7	16.1	16.3	15.7
Car 24	17.1	13.9	16.9	16.2	16.1	15.5
Car 25	14.7	13.1	14.6	14.8	14.5	14.3
Car 26	16.9	13.6	16.9	16.4	16.5	15.7

Constant Speed economy numbers are interpolated or extrapolated from Constant Speed 50 mph and 55 mph road test data.

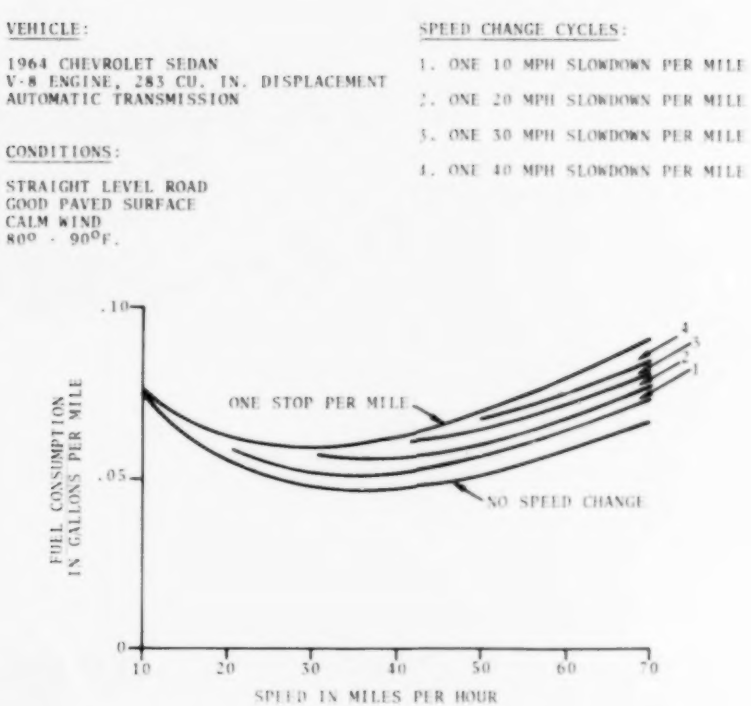
Source: Response of D.J. Bonvallet, General Motors Corp., to a Letter from Charles Gray, Jr., U.S. Environmental Protection Agency, Part Entitled "Fuel Economy Comparison".



Source: G. J. Huebner, Jr., and D. J. Gasser, "General Factors Affecting Vehicle Fuel Consumption," (paper presented at National Automobile Engineering Meeting, Society of Automotive Engineers, Detroit, Michigan, May 15, 1973).

Figure 2 Road Load Economy Versus Driving Speed

Unfortunately, since fuel economy does change with speed, knowledge of average speed alone will not allow fuel economy estimates to be made, even when simple combinations of steady speeds are driven on the track or dynamometer. For example, consider a sub-compact vehicle which operates at a steady speed of 40 mph. According to figure 2 its fuel economy would be about 41 miles per gallon. If the same vehicle operated at 20 mph for about 36 minutes and at 70 mph for about 24 minutes, the vehicle will have traveled about 40 miles in one hour, the same average speed as above. This vehicle gets about 25 miles per gallon at 70 mph and about 37 miles per gallon at 20 mph. The average fuel economy for this 40 mile trip is about 28 miles per gallon, which is much lower than the 41 miles per gallon obtained at the steady 40 mph speed. Figure 3 shows the effect of speed deviations on fuel consumption. Note that the data are plotted as fuel consumption,



Source: "Running Costs of Motor Vehicles as Affected by Road Design and Traffic," Paul J. Claffey, National Cooperative Highway Research Program Report 111.

Figure 3 Effect of Speed Change on Fuel Consumption - Chevrolet, 4,400 lb G.V.W.

the inverse of the plot of figure 2. When plotted on the same basis, the steady speed data are comparable. With a 40 mile per hour speed and one 10 mph slow down per mile, fuel economy changes from 21.3 miles per gallon to 19.2 miles per gallon a change of almost 10%. With one full stop per mile the fuel economy is 16.1, a change of about 24%. It can be seen that minor speed variations have a significant effect upon fuel economy.

Studies[4,7] show that the average vehicle speed for rural driving is between 46 and 56 mph. Table 4 and figures 4 and 5 are from chase car data provided by GM. Note from figure 5 that idle is the single most prevalent mode and that idle time is not represented in either the table 4 or figure 4. From their survey data[4], GM generated two customer derived driving schedules. One

TABLE 4 CHASE CAR DATA SUMMARY

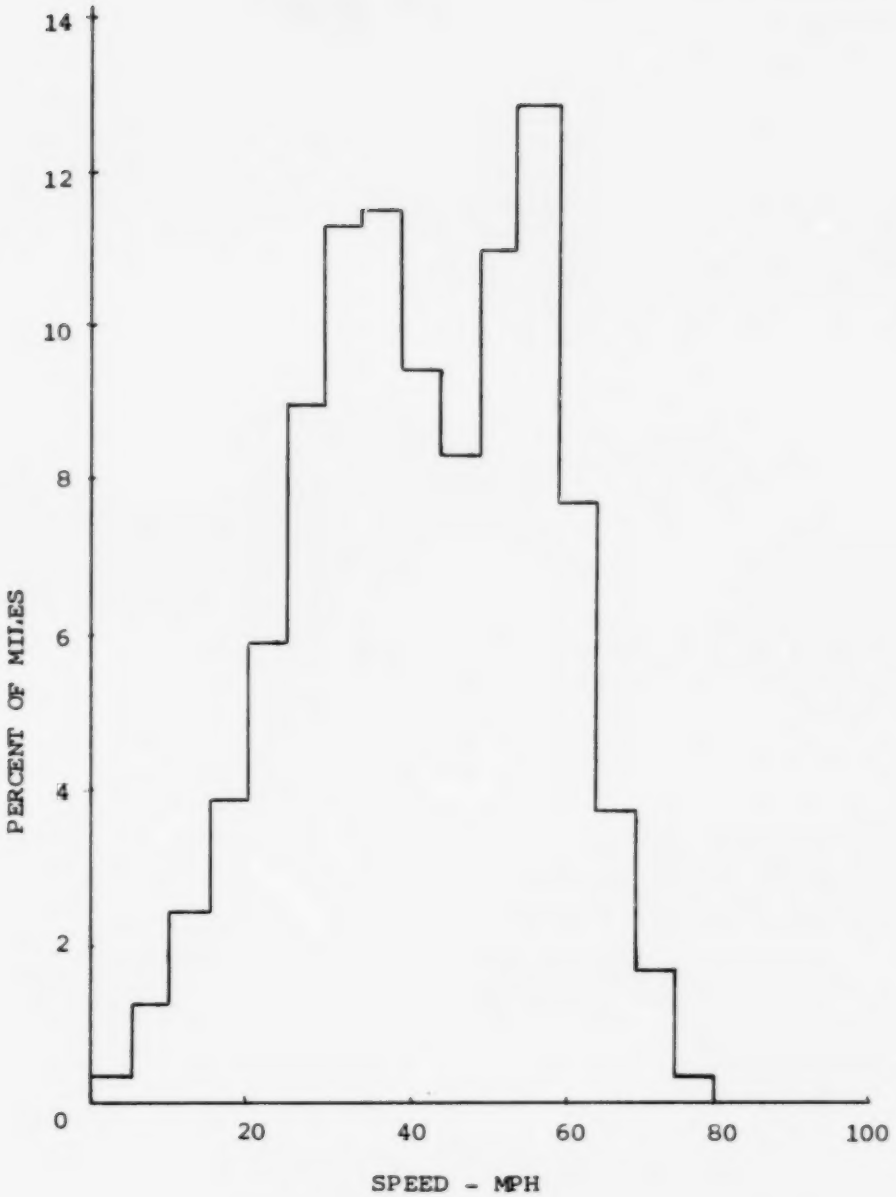
Road Type	Ave. Spd.	Full Stops/ Mile	Time (Min.)	%	Miles	%
Unpaved - Rural	24.497	0.546	13.	0.	5.	0.
Unpaved - Sub	17.711	0.370	9.	0.	3.	0.
Rural Highway	44.698	0.102	655.	5.	488.	8.
Sub - No Curb	21.455	0.883	70.	1.	25.	0.
Sub - Curb	18.952	1.233	285.	2.	90.	1.
Sub - Shop Cent	11.592	5.096	125.	1.	24.	0.
Sub - Artery	28.573	0.822	2107.	16.	1003.	16.
Urban	17.161	1.954	755.	6.	216.	4.
Urban - Artery	22.993	1.408	3988.	31.	1528.	25.
Cen Bus Dist - P	12.436	4.349	1024.	8.	212.	3.
Cen Bus Dist - NP	17.178	2.710	155.	1.	45.	1.
Strip - Comm	22.197	1.468	1221.	10.	452.	7.
Express - Bus RT	46.742	0.114	1093.	9.	852.	14.
Expressway	53.120	0.035	1337.	10.	1184.	19.
			12837.	100.	6127.	100.

Source: Response of D. J. Bonvallet, General Motors Corp., to a letter from Charles Gray, Jr., U.S. Environmental Protection Agency, part entitled "Fuel Economy Comparison."

schedule was called the "customer derived artery schedule". It has an average speed of 21 mph. The second was referred to as the "customer derived highway schedule". This schedule has an average speed of 52 mph. Further analysis of these data may result in modification or updating of these driving schedules.

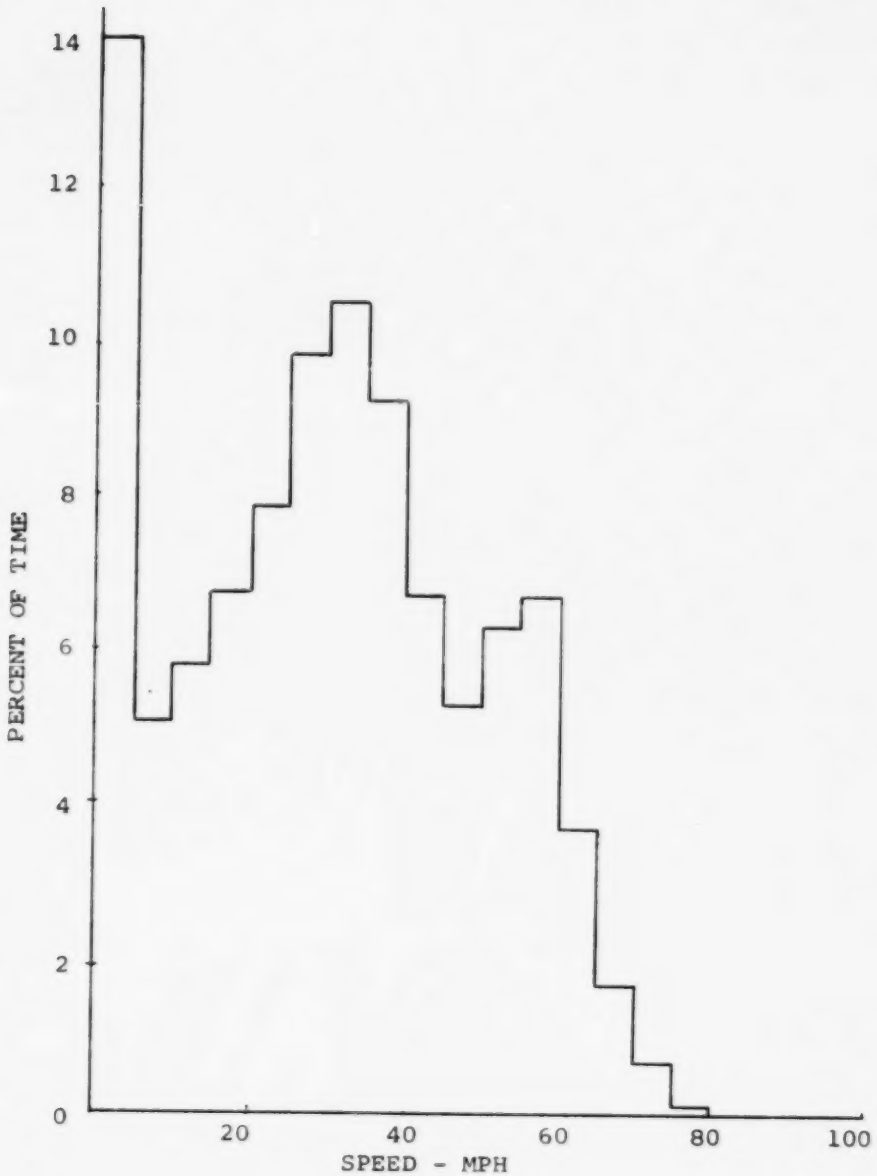
2. Acceleration, Deceleration and Idling

No real life trip consists of just one steady speed of operation. Even the simple trip simulations which use two or three steady speeds require transient operations (acceleration-deceleration) to get the vehicle from one speed to the next. So, acceleration-deceleration and idle are constantly a part of the real life driving and variation in these factors cause variations in fuel economy. For example, one study[10] evaluated the effect on fuel economy of operating the vehicle at three different acceleration rates. The vehicle was driven over a simple city route at each of the three acceleration rates (slow, 3 ft/sec^2; normal, 6 ft/sec^2 and high, 12 ft/sec^2) and fuel economy



Source: Response of D. J. Bonvallet, General Motors Corp., to a letter from Charles Gray, Jr., U.S. Environmental Protection Agency, part entitled "Fuel Economy Comparison."

Figure 4 Percent of Miles Travelled in Speed Bands



Source: Response of D. J. Bonvallet, General Motors Corp., to a letter from Charles Gray, Jr., U.S. Environmental Protection Agency, part entitled "Fuel Economy Comparison."

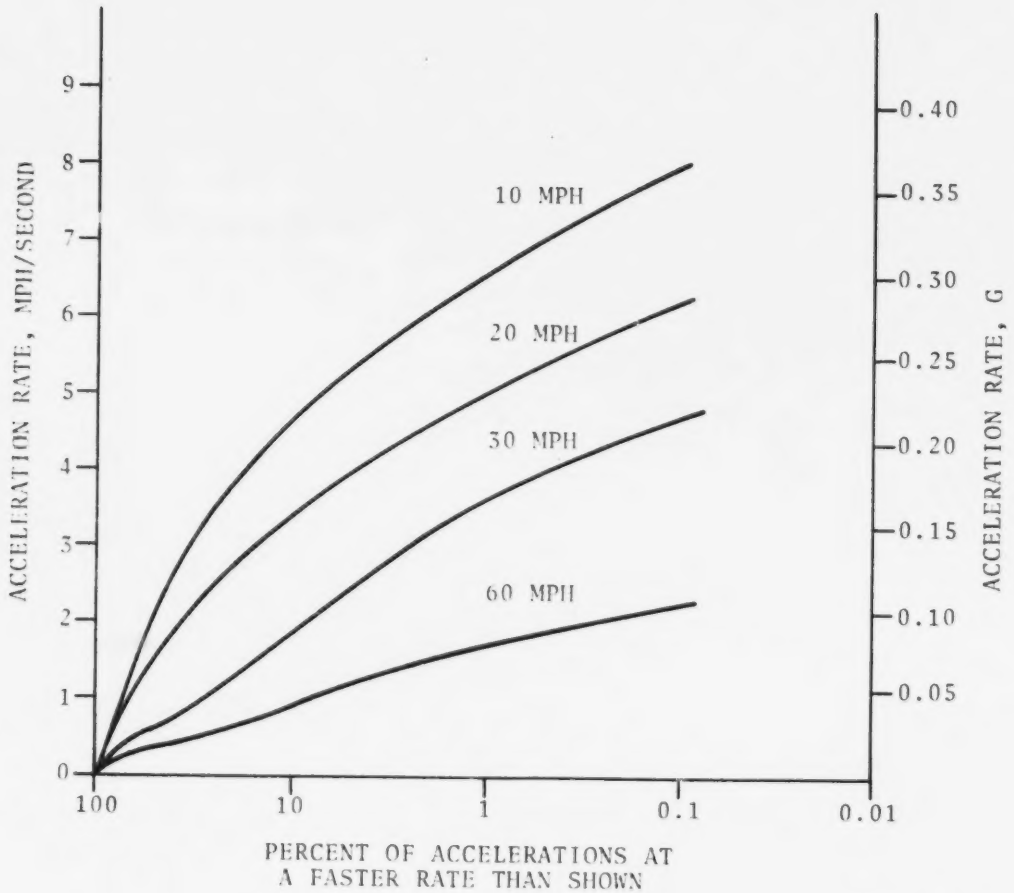
Figure 5 Percent of Time in Speed Bands

measurements were compared. Fuel economy at the normal acceleration rate was about 16 miles per gallon. At the low acceleration rate fuel economy was about one mile per gallon better and at the high acceleration rate, the fuel economy was about one mile per gallon worse than the normal rate. The extreme spread was more than a two mile per gallon difference. Figures 6 and 7 show the distribution of acceleration and deceleration rates combined for real life traffic in five cities.

From a fuel economy point of view, idle is non-productive. Fuel is consumed during idle, but no distance is accumulated. The amount of fuel consumed is dependent upon the accessory power requirements and the drive system friction losses. If the engine were stopped each time the vehicle was stopped, fuel economy might be improved, except that a significant amount of fuel is consumed during starting and in any case the major accessories (power steering, air conditioning, battery charging circuit) will not function when the engine is off. The amount of idle included in any trip affects both the fuel economy and the average trip speed. Idle is an urban phenomenon, ranging from 10 to 19% of total urban trip time[7]. The GM chase car data[11] showed an idle time of 14% of total time (figure 5) which is biased slightly to the low side, since the chase car did not usually account for the idle at the start of the trip and sometimes missed the idle at the end of the trip.

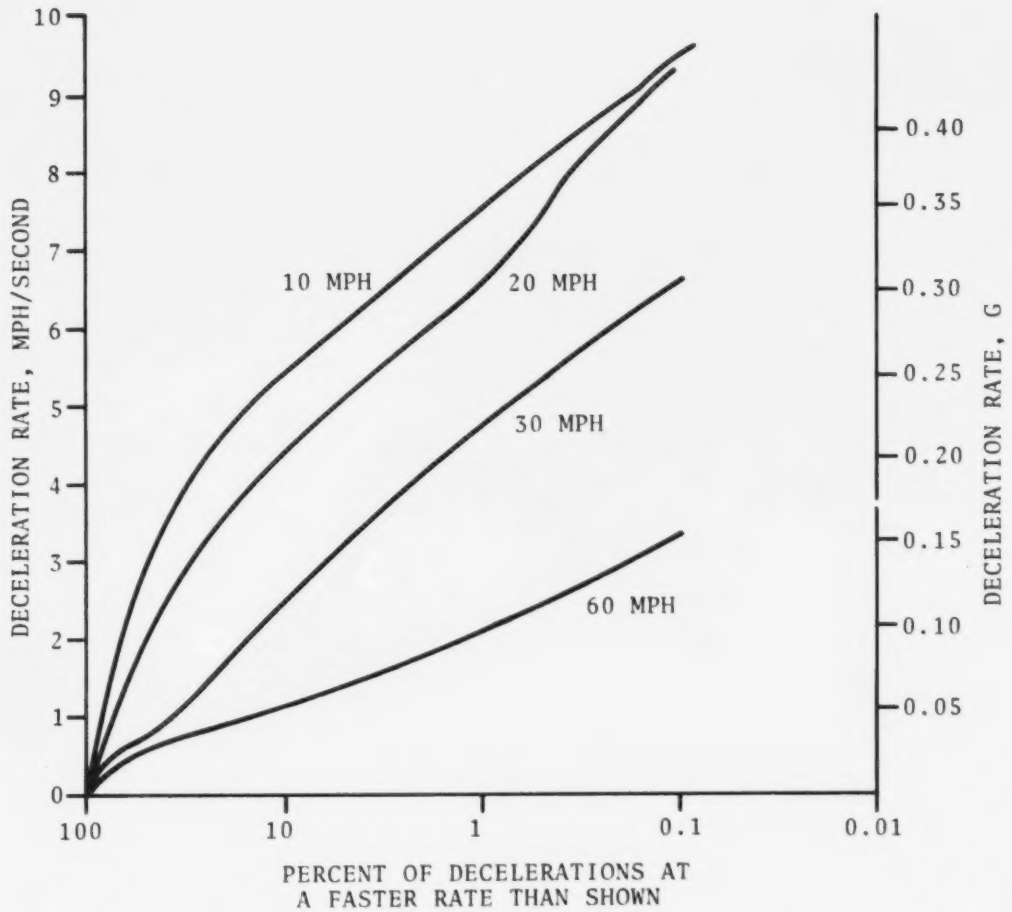
3. Stops Per Mile

Idle is important not only on the basis of the amount of time devoted to idle but is also important on the basis (independent of idle length) of the number of idle periods or stops which occur during the trip. This parameter can be conveniently described by the number of stops per mile. From figure 3, the effect of stops per mile upon fuel economy was demonstrated, with a base speed of 40 mph one stop per mile reduced fuel economy by 24% compared to no stops per mile. Figure 8 presents a typical relationship between stops per mile and average speed for both actual traffic and for simulated driving. Over-plotted on this graph for reference, are the values for various driving schedules.



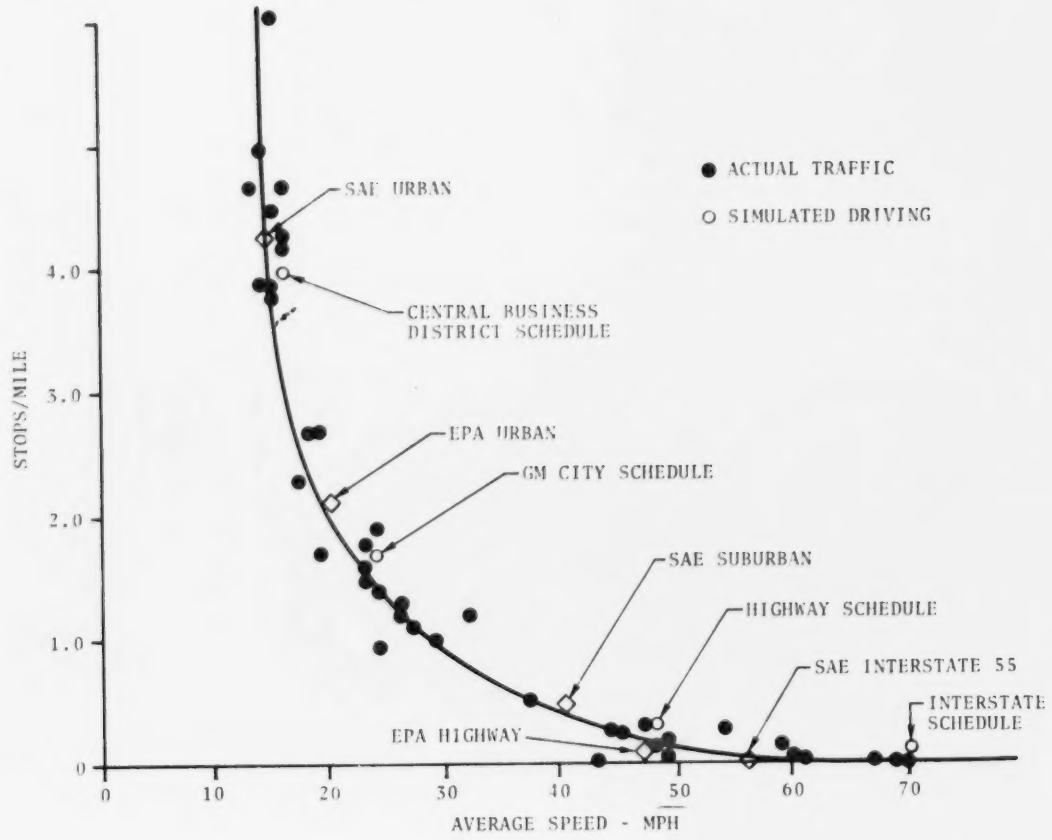
Source: Vehicle Operations Survey, Scott Research Laboratories, Inc., Volumes I and II.

Figure 6 Distribution Functions of 5-City Composite Accelerations at Various Instantaneous Speeds



Source: Vehicle Operations Survey, Scott Research Laboratories, Inc., Volumes I and II.

Figure 7 Distribution Functions of 5-City Composite Decelerations at Various Instantaneous Speeds



Source: GM Memorandum Report No. PG-34403, "Synopsis of Fuel Economy Meeting with Department of Commerce," Jack A. Arnold, Ronald A. Davis, William S. Freas, and Thomas M. Johnson.

Figure 8 Phoenix Arizona Average Speed Vs. Stops/Mile

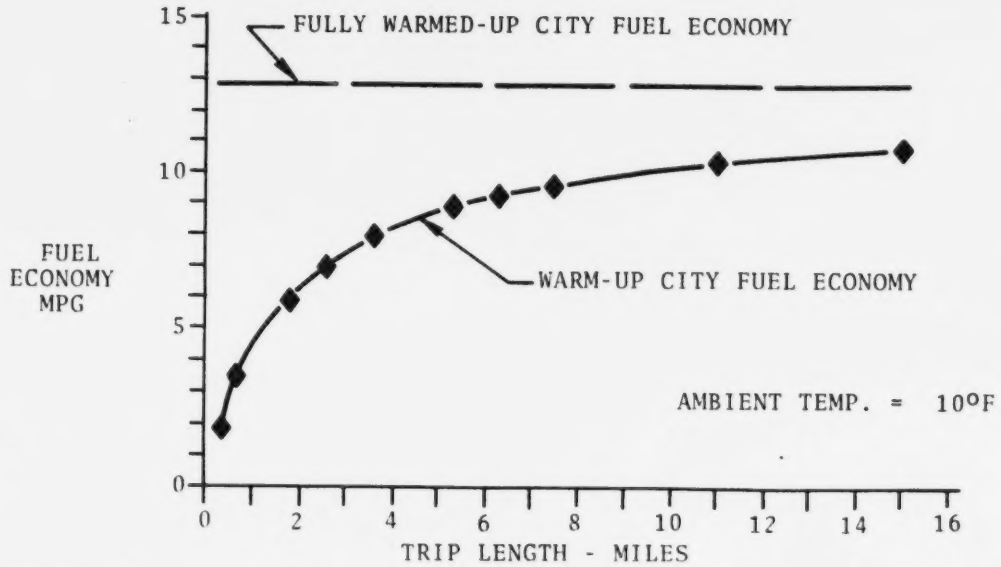
References 4 and 11 also provide more extensive data which show the same relationship and which show that the relationship is a continuous function from low speed to high.

4. Trip Length

The fact that trip length affects fuel economy may not be apparent. Trip length and other trip characteristics, such as trip purpose and average trip speed are closely interrelated and these combined, interrelated characteristics affect fuel economy. For example, a shopping trip will have a much different trip length than will a vacation trip. Other characteristics of a shopping trip, type of traffic, average speed, etc., are also different than for a vacation trip. These combined characteristics have an effect upon fuel economy. The generalization can be made that as trip length increases so will fuel economy, up to the maximum economy which can be expected from that vehicle. The relationship between engine operating temperature and trip length will be discussed in the next section.

5. Effect of Ambient Temperature on Fuel Economy

In real life, vehicles must expend energy to overcome internal friction. Internal friction is greater when the vehicle is at ambient conditions than when the vehicle is at its stabilized operating temperatures. Figure 9 illustrates the significance of this effect. As illustrated in figure 9, the effect of a frigid start (10°F) depends upon the length of the trip, such starts have more effect upon a short trip than on a long trip. FPA urban fuel economy results are presented in reference 12. The report presents both cold starts (68°F) and hot start data for EPA tests. Comparing the first 3.59 miles of the cold (68°F) trip to the first 3.59 miles of the hot trip produces a ratio of hot to cold fuel economy of 1.23 for an average for years 1966-72 of the sales weighted fuel economies of each year. The standard deviation of 1.6% of the mean indicating that vehicle model year had little effect upon the ratio of hot to cold starts. For the complete 7.5 mile cold trip compared to the complete 7.5 mile hot trip, the ratio of hot to cold for the sales weighted yearly data, averaged over the years of 1966-72, is 1.10



Note: Shown is cumulative fuel economy in city driving at 10°F beginning with a cold start. On a 4-mile trip the average fuel economy was only 8 mpg. Once fully warmed up, for example from the 11 mile point to the 15 mile point, fuel economy averaged 12.8 mpg.

Source: "Running Costs of Motor Vehicles as Affected by Road Design and Traffic," Paul J. Claffey, National Cooperative Highway Research Program Report 111.

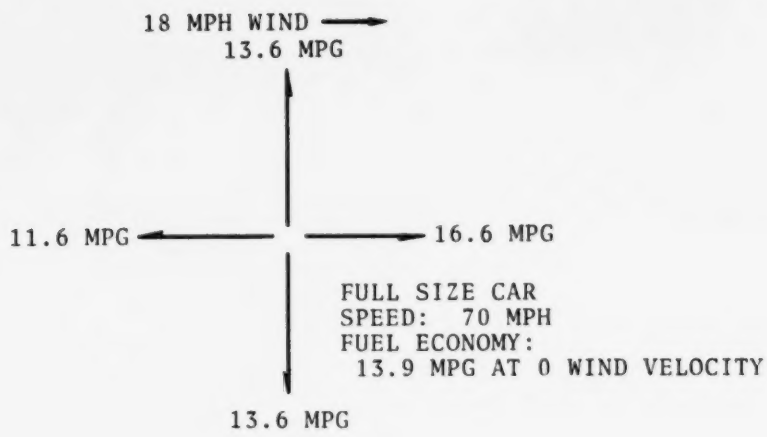
Figure 9 Warm-Up Fuel Economy

with a standard deviation as percent of the mean of 0.9%. Increasing the trip length from 3.59 miles to 7.5 miles reduces the hot/cold fuel economy difference from a ratio of 1.23 to a ratio of 1.10. Short trips, with long time intervals between trips produce poor fuel economy, especially in low ambient temperatures.

3.2 AMBIENT CONDITIONS

3.2.1 Wind

Reference 13 presents an extensive discussion of wind effects and concludes that on an aggregate nationwide fuel consumption basis, wind effects cause a 1-1.5% increase in fuel consumption. Figure 10 shows the effect of wind upon a typical vehicle operated at 70 mph.



Source: Jack C. Cornell, "Passenger Car Fuel Economy Characteristics on Modern Superhighways," SAE Report No. 650862, Report to the National Fuels and Lubricants Meeting, Society of Automotive Engineers, Tulsa, Okla., Nov. 2-4, 1965 (New York: Society of Automotive Engineers, 1965).

Figure 10 Effect of Wind On High Speed Fuel Economy

3.2.2 Temperature

Ambient temperature has an effect on both cold start and warm vehicle fuel economy. Increasing temperature increases fuel economy. For a warmed up vehicle with a fuel economy of about 15 mpg, an increase in temperature of about 60°F will cause a fuel economy change of about 1 mpg.[12] In another study, for a 4000 pound GVW vehicle operating at 40 mph, a 60°F change in temperature caused an 11% change in fuel economy.[14]

3.2.3 Humidity

Some data are available to indicate that humidity changes affect fuel economy. One study reports a fuel economy decrease of 0.069% for each humidity increase of one grain of water per pound of dry air.[15] Others have reported similar effects although some doubt that such an effect exists.

3.2.4 Barometric Pressure

Variations in barometric pressure cause variations in engine efficiency and aerodynamic drag. The magnitude of the effect depends upon vehicle operating speed and is low enough at urban speeds that it is negligible. For high speed driving the factor causes an adjustment of 1.4% for each inch of mercury change in barometric pressure.[4] The correction factor indicates that decreasing pressure results in increasing fuel economy. This relationship may not hold true when comparing fuel economy at altitudes which differ by more than 2000 feet (2 inches of mercury change). Reference 14 states that limited data show that, "Above 2000 feet, however, there is a small increase in fuel consumption for altitudes up to 3000 feet, followed by a sharp rise in fuel consumption between 3000 and 4000 feet." Reference 12 shows an 8% decrease in fuel economy for Denver, at about 5200 feet as compared to four low altitude cities.

3.3 ROAD CONDITIONS

It is intuitively obvious that road conditions, surface roughness, grade, presence of snow and ice affect fuel economy and these effects have been studied.

3.3.1 Surface

Road surface texture and condition also affect fuel economy. For a 4,400 pound GVW vehicle operating at 40 mph on a badly broken and patched asphalt road as compared to a good concrete or asphalt surface fuel economy is decreased by about 24%.[14] Driving on a dry gravel road caused a 37% decrease in fuel economy.[14] The presence of snow and ice on the road surface decreases fuel economy. Table 5 illustrates the magnitude of this effect. Note that the table is presented in terms of fuel consumption.

TABLE 5 CORRECTION FACTORS TO ADJUST PASSENGER CAR FUEL CONSUMPTION FOR ICE AND SNOW CONDITIONS

Speed (mph)	Dry Pavement	Very Slippery Hard-Packed Snow	Hard-Packed Snow on Ice With Bumpy Surface	New Snow on Hard-Packed Snow (in.)				
				1/2	3/4	1	1½	2
20	1.00	1.23	1.30	1.36	1.43	1.47	1.51	1.60
30	1.00	1.16	1.20	1.28	1.22	1.35	1.45	1.54
40	1.00	1.11	1.14	1.20	1.23	1.28	1.40	1.48
50	1.00	1.06	1.10	1.12	1.18	1.24	1.34	1.45
60	1.00	1.04	1.08	1.10	-	-	-	-

Source: Passenger Car Fuel Consumption as Affected by Ice and Snow, Paul J. Claffey, Task Force on Application of Economic Analysis to Transportation.

3.3.2 Grade

Plus grades decrease fuel economy and minus grades increase fuel economy. A 4,400 pound automobile operating at 40 mph on a +4% grade had a fuel economy decrease of about 36%.[14]

4. DISCUSSION OF TEST AND MEASUREMENT METHODS

The following sections compare the salient advantages and drawbacks of: (1) where the fuel economy test is conducted (a public road, an automotive test track, or a chassis dynamometer); (2) three alternative methods for determining fuel consumption during a given test; and (3) several techniques for obtaining a quantitative indication of vehicle road load (i.e., the total power expended in moving the given vehicle at various speeds over level roads) for use in adjusting the power absorption unit of a chassis dynamometer. The total power expended in moving a given vehicle at various speeds over level roads consists of power required to overcome vehicle inertia during acceleration, the power required to overcome aerodynamic drag, and the power required to overcome tire and drive train friction.

4.1 TEST LOCATION: ROAD/TRACK/DYNAMOMETER

4.1.1 Road Test

In principle, public roads should be an ideal place on which to conduct fuel economy tests since no capital or maintenance costs are charged to the test and anyone who wishes to conduct fuel economy tests may do so without access to special facilities. Also, road surfaces will be typical of at least a portion of the roads on which the general public drives. The vehicle, of course, sees the correct power demands on the road; the vehicle inertia, aerodynamic drag, internal friction and tire-road interface are all real life conditions. When other conditions are ideal and the vehicle is properly operated over the correct road route, with the correct traffic situation and good ambient conditions, good fuel economy measurements can be expected. However, testing on public roads has serious drawbacks involving test reproducibility, comparability, and safety.

It is obvious that any test used to determine vehicle eligibility for sale, or quantitatively specifying the fuel economy

of a vehicle for labeling purposes must provide as reproducible a measurement of each vehicle's performance as feasible. To achieve reproducibility of fuel economy, the driving cycle (speed versus time) which the vehicle is required to follow must be adhered to as closely as possible from test to test. Any deviation from the driving cycle caused by other traffic on the road could be expected to introduce significant variations in test results. Furthermore, wind conditions can be expected to vary from point to point along the test road. Wind and other ambient conditions can be expected to change also from day to day or even during a single day. Such variations in wind and other ambient conditions would introduce additional variations in test results.

In the definition of vehicle road load given above, it was stated that this applies to level road operation. In many large areas of the United States, it is difficult or impossible to find portions of public road of adequate length for fuel economy tests which are level or even of uniform slight grade (less than 0.5 percent, i.e., rising or falling less than 0.5 per 100 feet of length). Therefore, one cannot anticipate finding suitable sections of road near each of the several organizations which will be involved in fuel economy testing.

Finally, any fuel economy driving cycle will involve a precisely defined program of starts, different accelerations and speeds, and stops at various intervals. In general, any such driving cycle would be inconsistent with normal traffic patterns on any public road. The sudden stops, periods of idling, starts, and arbitrary speeds which must be adhered to rigorously would introduce serious, perhaps intolerable, hazards to the safety of both the general public and the test vehicle operator.

4.1.2 Track Test

The use of a test track, closed to public access, eliminates many of the safety and operational objections cited in relation to testing on public roads. As with road testing, track testing also treats the vehicle in its natural environment; vehicles, correctly operated on a properly designed track with similar power demands to those encountered in actual use.

However, in order to give satisfactory results, such tracks would have multiple lanes with different bank angles (for different speeds), would require circumferential lengths of at least 2 miles, and would occupy a minimum land area of about 0.42 square miles (170 acres). Construction of such tracks clearly would be quite expensive. Maintenance and operating costs would add to the expense of the fuel economy test program. Contracting a facility to conduct the testing would be a possible alternative, however, the General Accounting Office (GAO) estimates such a program would cost between one and two thousand dollars per test.[16] Manufacturers could conduct the testing themselves, since most auto manufacturers have test tracks of suitable dimensions (generally substantially larger than indicated above), which were used for engineering development purposes long before fuel economy assumed its present public importance. These tracks are primarily used for such purposes and also for exhaust emissions durability and other related tests. The addition of large numbers of fuel economy tests on these tracks may be possible, but very likely would impose operational difficulties and some test variations. In any case, only the manufacturers possess such tracks (except for a test facility built by the State of Ohio).

Another type of track which might be available for fuel economy testing is the automobile race track. However, such tracks are configured primarily for the demands of that sport, high speed operations, and are really not suitable for fuel economy testing. Economic considerations, such as the large costs of either building or renting such a facility, also make the use of an automobile race track unattractive.

As with roads, virtually all tracks are exposed to wind and weather. When winds exceed modest velocities and/or are gusty, and when temperatures are extremely high or low, fuel economy results are undesirably affected. Inclement weather can also delay test schedules for days at a time. Testing at conditions other than standard (which must be done to allow reasonable utilization of the facilities) requires that the data be corrected to the standard conditions by use of correction factors. Such

correction equations are empirical, cycle specific, and require continuing verification.

Another problem with track testing is that all of the test equipment must go with the vehicle or sophisticated data transmission equipment must be used to transmit data to a stationary facility. Adding equipment to the vehicle (for example, a strip chart recorder to record speed so that cycle speeds can be verified) adds weight and electrical loading which may bias test results.

A subtle problem which exists with track testing but not with dynamometer testing is the availability of suitable test vehicles. For track testing the vehicle must be of the correct aerodynamic configuration and correct weight. For preproduction testing, it may be difficult to obtain the correct preproduction vehicles far enough in advance of production to allow track testing for fuel economy prior to vehicle introduction. Dynamometer testing, on the other hand, requires only that the vehicle have the correct drive train since accurate engineering estimates of production vehicle weight (as is currently done) and aerodynamic drag can be used to set the dynamometer power absorption characteristics.

Rigorous concentration of the driver on following the prescribed driving cycle can lead to track safety problems. Attending to the other demands of operating a moving motor vehicle inevitably detracts from the attention the driver can devote to vehicle speed control and timing. Hence, complex driving cycles with continually-varying speed requirements, representative of actual vehicle use, are difficult to execute with precision and repeatability.

4.1.3 Dynamometer Test

An automotive chassis dynamometer ("dyno") is a mechanical device intended to permit operation of a stationary vehicle in a manner that accurately simulates the vehicle's operation on a straight road. The vehicle's driving wheels are positioned either in the "saddle" between a pair of small rollers (generally 8 to 12

inches in diameter) or directly over the axis of a single large roller (usually 4 to 7 feet diameter). The rollers are free to rotate in bearings, and are connected to adjustable power-absorption devices which generate frictional drag on the vehicle's rotating wheels and dissipate the resultant power. These power absorbers are adjustable as to the load applied at any speed, to compensate for different vehicle characteristics. The resisting torque applied to the roller(s), and roller speed, are measured to indicate the horsepower (HP) absorbed by the dynamometer. Flywheels of different sizes can be connected to the dynamometer roller shafts to simulate the inertia the vehicle would exhibit in acceleration and deceleration on the road (and thus reproduce the associated power demands on the vehicle's engine).

The power required to overcome aerodynamic drag varies with the size and shape of the vehicle, approximately as the cube (third power) of speed. Drag is inconsequential at low speeds and dominant at highway speeds on level roads. In addition to aerodynamic drag, power is required to overcome tire and drive train friction; this "rolling load" power is approximately proportional to weight, and increases somewhat more rapidly than the speed. Rolling load varies modestly with mechanical design, and significantly with tire characteristics. "Road load horsepower" is the sum of these power demands, plus any vehicle accessory power requirements, at any speed.

The power absorption characteristic of a dynamometer is intended to be adjusted so as to accurately simulate the real world power demands placed upon the vehicle. Since the vehicle, tested on the dynamometer, is removed from its natural environment, it cannot be assumed that vehicle power absorption is automatically correct. The dynamometer must be capable of simulating aerodynamic drag, inertia during acceleration, and tire friction. The ability of the dynamometer to simulate these power demands is related to the cost and complexity of the installation.

Probably, the most difficult aspect of simulating road testing is the correct simulation of the tire-road surface interaction. It has been suggested that single-roll dynamometers minimize this problem, and that adequate factors can be derived to correct cradle-roll loading, if it is otherwise acceptable. The significance of this interaction is still a mater of disagreement within the motor vehicle and dynamometer manufacturing industries and is an area which deserves further study.

Despite the problems cited above, chassis dynamometers offer several advantages over road or track facilities for fuel economy measurement. The dynamometer and test vehicle can be operated indoors under controlled, reproducible environmental conditions (except, in general, for barometric pressure) thus wind, temperature and precipitation need not influence test results or scheduling. The vehicle is stationary and the driver therefore may concentrate fully on following the drive cycle, thus allowing transient drive schedules representative of actual driving. Large, heavy, sensitive and/or high-power-demand instrumentation may be used which would not be feasible or possible to apply to on-road tests. With a properly-constrained vehicle, there is little safety hazard. Tests may be replicated at will to evaluate the variability of the test procedure versus that of the vehicle. There are a large number of available test facilities as compared to track facilities. The initial costs of dynamometer of adequate capability, and of the facility to house them, are far from trivial, but still are considerably less than those of test tracks. If fuel economy tests are combined with the federal emissions certification test program, the incremental cost is small, as evidenced by GAO's estimate of $73 per test for EPA to conduct highway cycle fuel economy determination during fiscal year 1975.[17] However, if the fuel economy test program is separate from the federal emissions certification program, each test would cost roughly $700. If new facilities were required, the start-up cost for one dynamometer test cell, which can test approximately 20 cars per 40-hour week, is approximately $460,000.

4.1.4 Conclusion

The choice of an appropriate location for fuel economy testing is strongly dependent on the scope of the testing program. Each of the locations discussed here is most applicable to a particular type of program.

Road tests (on public roads) are applicable primarily to high-speed highway fuel economy determinations where a high degree of accuracy and repeatability is unnecessary. Highly precise urban or highway measurements, which are necessary in a regulatory program, cannot be readily accomplished via road tests.

Track tests are most applicable to relatively steady-speed fuel economy measurements or to measurements made with simplified driving schedules. The track is especially useful in research work, where the effects of varying tires, weight, etc. on a particular vehicle's fuel economy can readily be studied. Track tests are not applicable to procedures which employ complicated driving schedules because of safety and repeatability problems. Because the instrumentation necessary for track tests must be installed in and calibrated for each test vehicle, this location is also undesirable for test programs which encompass a large fleet of vehicles.

Chassis dynamometer tests are most applicable to large vehicle fleets which are tested over various driving schedules. Because the test vehicle is stationary, the driver is free to concentrate on following any driving cycle, no matter how complex. Large numbers of vehicles are more easily tested since the required instrumentation can be permanently installed and routinely calibrated in the test cell. A more specific application of the dynamometer test is the situation where fuel economy and emission information must be obtained simultaneously, in which case, the dynamometer test is the only practical alternative. Dynamometer tests, however, are not applicable to research studies involving tire characteristics or aerodynamic considerations.

In view of the above discussions, the use of the dynamometer tests is deemed preferable for the regulatory - type program under

consideration. This location offers the most cost-effective combination of versatility and repeatability, which are essential in such a program.

4.2 FUEL CONSUMPTION: WEIGHT/VOLUME/CARBON BALANCE

Since fuel economy is defined as the quotient of distance "traveled" divided by quantity of fuel consumed, accurate determination of fuel used during a test is vital. Unfortunately, this is not as simple a procedure as it might appear at first glance. The following section discusses some of the complexities encountered in this type of measurement.

In some modern automobiles, the fuel pump delivers more fuel than the engine requires and the excess is returned to the fuel tank (most diesel engines also do this). For these vehicles, it is not sufficient merely to measure the fuel drawn from the fuel tank. When an engine which is at operating temperature, is shut off several interrelated events occur which result in a loss of fuel from the carburetor bowl and the fuel line between the carburetor bowl and the fuel pump. Upon cranking the engine to start it, the empty volume of fuel line and float bowl must be refilled with fuel which is not used to power the vehicle, since that volume will remain in the system at the end of the test. This quantity of fuel may not be insignificant in a fuel economy test. Conversely, the (fuel) evaporation control system of modern cars store fuel vapors which are returned to the engine without being measured.

The density of gasoline (or of diesel fuel) changes fairly rapidly with temperature (about 0.6 percent per 10^{o}F). Gasoline contains some constituents of rather high vapor pressure which tend to create bubbles of vapor in a fuel line; the density of those bubbles, which may be measured as if they are liquid, is less than 1 percent of liquid fuel density.

Three principal techniques have been used for determination of the quantity of fuel consumed by a vehicle. Two of these involve a direct measurement of fuel, in terms of either volume

(most applicable to on-road use) or weight. The third method, the "carbon-balance" technique, is an indirect approach which determines from exhaust emissions the total weight of carbon in the gases leaving the engine.[18] The weight of carbon per unit weight or volume of gasoline can be determined (or, since it doesn't vary greatly, sometimes is assumed to be constant). Then the total weight of carbon in the products discharged, if it has been determined with sufficient accuracy, can be used to calculate the quantity of gasoline which must have been burned to produce those products. The carbon-balance technique is applicable presently only to a dynamometer test, in which the vehicle is stationary.

These three techniques are discussed individually below.

4.2.1 Fuel Weight Determination

The weight of fuel consumed during a test is determined by weighing a vessel containing the fuel both before and after the test. This technique appears to offer little chance for error, assuming that a weighing device with adequate sensitivity and resolution is used. Yet previous fuel economy tests using this technique have shown rather poor repeatability in replicate tests; fuel consumption data were not consistent with concurrent measurements of fuel usage by volume or carbon-balance.

In many of these earlier tests, it appears that much of the errors may have been due to inadequate control of the test procedures. Also, the problem of an incompletely-filled fuel system during engine starting, which was mentioned above, often was known to have afflicted the test. Vapor bubbles in the fuel line at the beginning or end of the test also will result in an incompletely filled system, and again introduce variance.

More recent and more carefully-controlled weight (gravimetric) tests have pressurized the fuel system of the vehicle just prior to starting the test, by means of a separate fuel pump. This has served to eliminate the unfilled fuel system. The repeatability of these later tests is better than $\pm 2\%$.[19]

Another potential source of error in the gravimetric technique is evaporation of fuel from the weighted container during the test. The magnitude of this error should be relatively small and should be controllable, but it is an item to be considered in an experiment.

Gravimetric measurement of fuel consumption are most conveniently used with dynamometer tests, but can be employed in an on-the-road test, if a strain-gage or similar weighting technique and a small accessory fuel tank are used. For maximum precision it may be necessary to stop the vehicle briefly for each weight measurement.

4.2.2 Fuel Volumetric Determination

Several high-precision volumetric flow meters are available for measuring fuel consumption. These are positive-displacement totalizing meters which indicate the volume of fuel that has passed through since some earlier time, in the manner of a household water meter. These meters do not indicate the instantaneous flow rate, however, for most automotive fuel economy test procedures, this is no drawback, since the meter simply is read at the beginning and end of the test (or reset to zero at the beginning).

Since fuel density changes appreciably with temperature, the "gallons" in a miles-per-gallon calculation must be corrected to a standard fuel density; hence, it is necessary to record the temperature of the fuel being measured. Certain of these meters impose substantial pressure drops across the meter, and thus require an auxiliary pump to supply the differential. In such cases, care must be taken not to upset the fuel system of the vehicle on which the meter is being used. As with a weight measurement, consideration must be given to the possibility of vapor bubbles in the system; and fuel return flow to the vehicle tank must be handled correctly when encountered. When it is desired to install these meters in the engine compartment of a vehicle, difficulties may be caused by the relatively large physical size of some of these instruments.

4.2.3 Carbon-Balance Fuel Determination

Solumetric measurements can be made to a precision of less than ±2%.[19] As outlined above, the carbon-balance technique determines the amount of gasoline consumed by measuring the weight of carbon-containing gases in the engine exhaust and calculating the weight and volume of gasoline which would contain that much carbon. The Federal emissions test procedure (FTP) requires dilution of engine exhaust, immediately after discharge from the exhaust system, with up to eight or more times as much air (to prevent condensation of water and other vapors). A portion of this air-and-exhaust mixture is collected throughout the test and subsequently analyzed for all carbon-containing compounds. Representative final concentrations might be: carbon dioxide (CO_2), 1.43 percent; carbon monoxide (CO), 307 parts per million, or 0.0307 percent; and hydrocarbons (HC), 106 parts per million, or 0.0106 percent, carbon equivalent.

Extremely accurate determination of the total weight of CO_2 obviously is crucial to the accuracy of fuel economy determined by this method. In the above example, the weight of CO_2 represents over 97 percent of the gasoline which this technique (Federal Test Procedure, Section 85.175-23) will indicate was consumed. Typical variability in CO_2 measurements is less than ±3%.[20]

It is generally conceded, and apparent from the above, that such a circuitous technique would not ordinarily be a first choice for a fuel economy measurement. However, for those cars comprising the emissions test fleet, the measurements are going to be made anyway; hence, consideration should be given to this technique. If the tester also is constrained from modifying the vehicle's fuel system, then the carbon-balance method becomes almost inescapable.

The carbon-balance technique does eliminate the two problems of (1) unfilled fuel system and (2) fuel return from the evaporation-control system. This results from the fact that this method looks only at what comes out of the engine. However, if the vehicle exhaust system has any leaks, some of the carbon

products will not be collected and the calculated fuel economy will be erroneously high. DOT has developed an exhaust leak check which can quantify exhaust leaks in a simple five minute test.[21]

As with the other two fuel-measurement techniques, the carbon balance fuel economy should be corrected for the actual heating value of the fuel used in the test. The density of the fuel at a standard temperature also should be measured, since the carbon-balance method calculates the weight of fuel used and converts this to volume via the fuel density. The other two methods require correction of the volume or density of fuel consumed to a standard temperature.

4.3 VEHICLE ROAD LOAD DETERMINATION

In the previous discussion of dynamometer testing, it was noted that the power absorption characteristics of a chassis dynamometer must be adjusted to correspond to the "road load" of the vehicle to be tested.

The road load of a vehicle may be defined as the sum of all dissipating forces acting on the vehicle. This is equal in magnitude but opposite in direction to the motive forces which must be exerted to maintain the vehicle at a constant speed on a level surface in still air. A complete description of the vehicle road load is therefore expressed in terms of a force versus speed curve. It is perhaps more traditional, at least from an engine design standpoint, to express road load in terms of power. However in practice, either on the road or on a dynamometer, force is almost always the parameter which is measured. Power is then computed from the force according to the equation:

$$P = f \cdot v$$

where

P = the power
f = the force
v = the velocity

A conversion constant may be necessary depending on the units of power desired. Since force is the measured parameter, it is more logical, particularly from a dynamometer standpoint, to discuss the road load as a force, eliminating the superfluous factor of v.

In the case of some simplier dynamometers the shape of the force versus speed curve is fixed, and the dynamometer operator only has the freedom to set this curve at any one speed-force point. That is, if the dynamometer is set to produce some desired load force at 50 mph it will automatically produce lessor load forces at lower speeds. The magnitude of these forces will be influenced by the chosen dynamometer set point and will be "reasonably appropriate"; however, they are determined by the construction of the dynamometer power absorber and cannot be controlled by the operator. More sophisticated dynamometers can be adjusted to fit a force versus speed curve through 2, 3, or 4 points. These dynamometers can be programmed to more precisely match the road load characteristics of any vehicle over a wide speed range, however for this advantage to be useful more information must be known about the vehicle road load and more care is required in the dynamometer adjustment than is necessary with the simplier dynamometer. In any case, it should be remembered that any dynamometer must be adjusted in some manner to correspond to the road load characteristics of the vehicle to be tested.

The question now arises, "How should the road load force versus speed function of a vehicle be determined?" It is necessary to choose a method to monitor some selected parameter which indicates the road load imposed on the vehicle. The parameter should be subject to accurate measurement, should allow an easy check on the validity of a dynamometer setting and should be sensitive to small variations in the vehicle road load. The parameter may quantify the road load directly, such that after possible corrections, a road load force versus speed curve may be calculated and this curve used to adjust the dynamometer. If the parameter does not directly identify the road load, then the vehicle must be operated on the dynamometer and the dynamometer adjusted to reproduce the on-road measurement of that parameter. This must be repeated each time the vehicle is tested on the

dynamometer, or measurements from the dynamometer must be used to determine a road load curve for the vehicle. It should be apparent that the choice of the road load parameter is an important consideration in evaluating various methods of measuring vehicle road load.

Several possible parameters or methods are:

a) Drawbar force

b) Drive wheel torque

c) Drive shaft torque

d) Coast down times (the speed versus time curve as the vehicle freely decelerates through a chosen speed range)

e) Engine intake manifold pressure (applicable only to 4 stroke naturally aspirated spark ignition vehicles)

f) Fuel flow

g) Wind tunnel.

These road load indicating parameters and the methods associated with using each are discussed individually below.

4.3.1 Drawbar Force

In this approach the vehicle being tested is towed by another vehicle and the force required to maintain the towed vehicle at a constant speed is monitored. This is the most conceptually straightforward approach, however several problems occur in practice. The most significant problem is the aerodynamic effect of the towing vehicle upon the towed vehicle. To reduce this effect to an acceptable level requires a very long tow line and subsequently a very large track, or at least a very long straight section of track, to satisfactorily perform the measurement. Any undesirable interaction between the towed and the towing vehicle will be related to the aerodynamic nature of each vehicle. This couples the possible error to the quantity the experiment is attempting to measure and compounds the seriousness of the problem.

Drawbar force may be a useful method to observe changes in road load as a parameter not related to the aerodynamic aspects of the vehicle, such as tires, is varied. However, drawbar force is not considered a satisfactory method of measuring total road load of a vehicle.

4.3.2 Rear Wheel Torque

In the rear wheel torque method, the force supplied to each rear wheel necessary to maintain the vehicle at a constant speed is monitored. This approach is as conceptually straightforward as the drawbar method, but since the test vehicle is supplying the motive power, it removes the very serious aerodynamic problem of the tow vehicle. Also, since the drive wheels are the last link in the drive train, no corrections to the measured forces are needed.

Unfortunately, the torque wheel method has several instrumentation problems. First, the torque wheel instrumentation is expensive; second, this method is not easily adaptable to a large class of vehicles. The torque wheel instrumentation must be inserted between the rear wheel hub and the rear wheel well. If adaptors are used to allow a single set of torque wheels to be used on vehicles with a variety of rear wheel bolt patterns, the magnitude of this problem increases. Moreover, the design of some automotive or truck wheels and hubs might prelude the use of standard torque wheels and require the construction of special torque wheels. In any case, if the tire is to remain in nearly the same position on the instrumented vehicle as it occupied prior to instrumentation, a special wheel would have to be purchased or made for nearly each model of vehicle tested. It may also be difficult to adapt torque wheels to front wheel drive vehicles.

Torque wheels are sensitive and may require frequent maintenance or calibration if subjected to unfavorable ambient conditions or to the severe loading of a wide open throttle acceleration or the shock of a hard shift of a manual transmission.

4.3.3 Drive-Shaft Torque

The drive shaft torque meter method is similar to the torque wheel approach but avoids the problem of requiring two expensive torque wheels by monitoring the total driving force in the drive shaft. This also avoids the problem of maintaining the appropriate rear tire position of the instrumented vehicle.

To insert a torque meter into the drive shaft of the test vehicle generally requires cutting a section from the original drive shaft, welding several flanges onto the remaining section, bolting the torque meter on to the flanges and balancing the assembly. Drive shaft torque meters may be sensitive to maintenance and calibration problems if subjected to severe transient stresses.

Several "clamp on" methods of measuring drive-shaft torque have been suggested but there are fundamental difficulties in this approach. Any dynamic force or torque measuring system senses the deformation of some member in the instrumentation system. In the case of a clamp on drive shaft torque meter, the drive shaft itself is the primary deforming member. But since the drive shaft must be designed to withstand severe loads, it can be expected to deform very little under the low speeds imposed by low speed steady state operation. The clamp-on drive shaft torque meter is fundamentally less sensitive than is possible with torque meter installed in the drive shaft. Furthermore, clamp-on drive shaft torque meters might present problems because of the mass of the instrument affecting the balance of the drive shaft or because of the clearance required for the attached instruments.

It should be noted that the torque measured in the drive shaft includes the losses encountered in the differential and the rear wheel bearings. Therefore, if this method is used to determine an algebraic expression for a road load function, it is necessary to determine these losses independently and to subtract them from the indicated drive shaft torque.

The drive shaft torque meter method is, in general, not applicable to front engine-front wheel drive vehicles or mid or rear engine rear wheel drive vehicles.

4.3.4 Coast Down Timing

The coast down timing method is conceptually different from any of the preceding methods. The road load force is the sum of the rolling resistance and the aerodynamic drag imposed on the vehicle. Under steady state conditions, the force supplied by the vehicle or by an auxiliary source, must be equal to this road load force to maintain the vehicle at a constant speed. In the preceding methods some measure of this steady state driving force is the parameter which is monitored. In the coast down timing method, the drag forces are allowed to freely act on the vehicle and the effect of these forces is measured by monitoring the change in vehicle speed. If the mass of the vehicle is known, then the road load force may be calculated from the measured deceleration.

During the coast down the drive train is being motored by the driving wheels; therefore, a correction for this loss is necessary, as is required by most other methods. However, since this is a non-steady state approach, the energy stored in the motion of the rotating components, such as the wheels, is being expended. This effect may be small, but it should be measured and the necessary corrections made.

There are two disadvantages of the coast down timing method. First is the greater number of corrections required to arrive at the road load from the measured parameters. Second, in general, the vehicle cannot be coasted down on the dynamometer as an accurate method of setting the dynamometer unless the dynamometer is capable of accurately simulating the correct value of inertia. This is generally the case with dynamometers using electrical inertia simulation but is not convenient with more common dynamometers which use mechanical flywheels to simulate inertia.

4.3.5 Manifold Pressure

Before the application of emission control system to engines, intake manifold pressure measurements at various constant speeds provided some indication of steady-state power produced by a conventional 4-stroke naturally aspirated spark-ignition engine. However, the control systems of modern engines frequently interact with, or cause significant variations in the intake manifold pressure. Furthermore, this parameter is sensitive to changes in such ambient conditions as temperature, barometric pressure, and humidity. In some instances the manifold pressure technique may be useful, but it is unlikely manifold pressure can be successfully applied to the majority of vehicles currently being produced.

4.3.6 Fuel Flow Rate

The rate of fuel consumption is a measure, but may not be a single valued measured, of the engine power produced. However, at a specific engine speed and load, fuel flow rate should be relatively constant and repeatable for a given engine if the engine has stabilized in temperature. Therefore, conceptually this parameter could be used to indicate road load.

The major difficulties with this approach is that fuel flow rate is sensitive to ambient effects, and may not be as sensitive to road load as would be desirable for a road load indicator.

4.3.7 Wind Tunnel

The road load of a vehicle is the sum of the aerodynamic drag, which is strongly velocity dependent, and the rolling resistance which is mainly velocity independent. It is therefore, at least feasible to measure these terms independently and then combine them as a measure of vehicle road load. This could be done by measuring the rolling resistance at near zero velocities which can be done in a small space, measuring the aerodynamic drag in a wind tunnel large enough to accommodate a full sized vehicle, and then summing these components.

The advantage of this method is that all measurements could be performed in a laboratory-like environment with at least some control over the ambient conditions. The major disadvantage is the extreme cost of such a facility. Also, it might be very difficult to simulate the stationary road-moving vehicle boundary effect, however, this would probably not be important if all vehicles were tested in the same manner.

The wind tunnel approach deserves some thought and consideration if it is deemed necessary to determine a measure of road load for each of a large number of vehicles delivered to a laboratory prior to testing for fuel consumption. It is not suggested as a feasible method for the immediate future.

4.3.8 Conclusion

The choice of a method to determine road load is strongly dependent on the reason for making the measurement or how the measured road load is to be used. If the road load measurement is to be used to design a vehicle, then the instrumentation need only be designed for a single vehicle or for a small class of vehicles, but must be very sensitive to small changes in the vehicle. In this case, the instrumentation can remain on the vehicle for a long period of time and if maximum accuracy is required, the on road measurement will be directly reproduced on the dynamometer as a method of setting the dynamometer. For this type of testing one of the torque meter systems would be the preferred choice.

If a laboratory is to test a large class of vehicles, possibly on different dynamometers, or if different laboratories are to test these vehicles, it is very convenient to have the road load expressed as an equation. If the road load is known in the form of the force to be required at the rear wheel or the power to be absorbed from the rear wheel, then this curve can be reproduced on any suitable calibrated dynamometer without the necessity of maintaining instrumentation on the vehicle, or the time required to duplicate the on road measurements as a method of setting the dynamometer prior to each test. Furthermore, if

the road load curve is known, and the range of possible dynamometer curves is known, then if the dynamometer cannot duplicate the road load equation exactly, it is at least possible to select the dynamometer curve which will minimize the error in the region of greatest interest.

If a road load equation is desired, most methods would require some corrections or duplication of the on-road measurement on a dynamometer. The additional corrections required for the coast down method, since coast down timing is a non steady state method, are not a major additional burden. Therefore, in the case of a large number of vehicles or diverse class of vehicles, coast down timing is considered the most satisfactory method, since this approach is the most universally applicable and require a minimum of instrumentation to be connected to the vehicle.

5. CURRENT TEST PROCEDURES

5.1 DYNAMOMETER BASED PROCEDURES

Two basic dynamometer procedures are available for measuring motor vehicle fuel economy. In response to a request in 1973 by the Environmental Protection Agency (EPA), the Society of Automotive Engineers (SAE) formed a fuel economy task force and charged it with development of SAE standard procedures for conducting fuel economy tests. This task force is currently compiling a recommended dynamometer test procedure. The other dynamometer procedure is one which EPA has used for several years for measurement of urban fuel economy and which EPA has recently expanded to include measurement of highway fuel economy. The basic characteristics, advantages and disadvantages of each are described below.

5.1.1 Proposed SAE Procedures

The SAE recommendations provide very detailed specifications for measuring a vehicle's fuel economy on a dynamometer.[22] This procedure consists of four basic steps: (1) determination of the vehicle's road-load characteristics, (2) adjustment of the dynamometer to accurately simulate those road conditions, (3) execution of the specified fuel economy driving schedule and measurement of the actual fuel consumed, and (4) correction of the observed fuel economy data for varying ambient and dynamometer conditions.

The determination of vehicle road load is perhaps the most sophisticated portion of the SAE procedure.[23] The test vehicle is driven on a flat, smooth road and allowed to coast-down from 70 to 15 mph. A minimum of six coast-downs is required to calculate average coast-down times over five 10 mph increments. These data are used to formulate a road-load equation which is then corrected for ambient temperature, humidity, and barometric pressure. Corrected coast-down times, to be used in the dynamometer simulation, are calculated from this corrected road-load equation.

In an attempt to increase the accuracy of fuel economy measurements, SAE has recommended very strict dynamometer calibration specifications. The basic road-load calibration is accomplished by running vehicle coast-downs on the dynamometer and adjusting loading controls until the dynamometer coast-down times match the corrected road coast-down data. Error limits for each vehicle are set at ±2% except for the interval around 50 mph, where the corrected road time must be duplicated on the dynamometer. Another significant SAE specification is the usage of a large, single-roll dynamometer capable of inertial simulation within ±5% of any vehicle's equivalent inertia. This specification cannot be met by commonly-used emission certification dynamometers.

Upon completion of the dynamometer calibration, the vehicle test is begun. Dynamometer driving schedules have not yet been specified by SAE, but their procedures are designed to accommodate any choice of driving schedule. Fuel consumption is measured either by volumetric flow or direct weight methods, which SAE specifications prescribe to be accurate within ±.25%. Test validity is established if the driving schedule time and distance specifications have been duplicated within ±1%.

In determining the actual fuel economy of the test vehicle, SAE recommends final correction to the fuel economy during the test. These corrections are designed to compensate for the test-to-test variability of ambient temperature, pressure, and humidity. Corrections are also recommended for dynamometer inertial and power setting inaccuracies. At the time of this writing, the correction factors for all of the above parameters had not yet been established by SAE.

5.1.2 EPA Procedures

The EPA approach to fuel economy measurement techniques is based on the well-established emission certification test procedures.[24] Fundamental steps of these procedures are: (1) usage of a standard dynamometer road-load setting for vehicles in specified weight classes (see Table 6), yet allowing specific vehicle road load determination at the manufacturer's option,

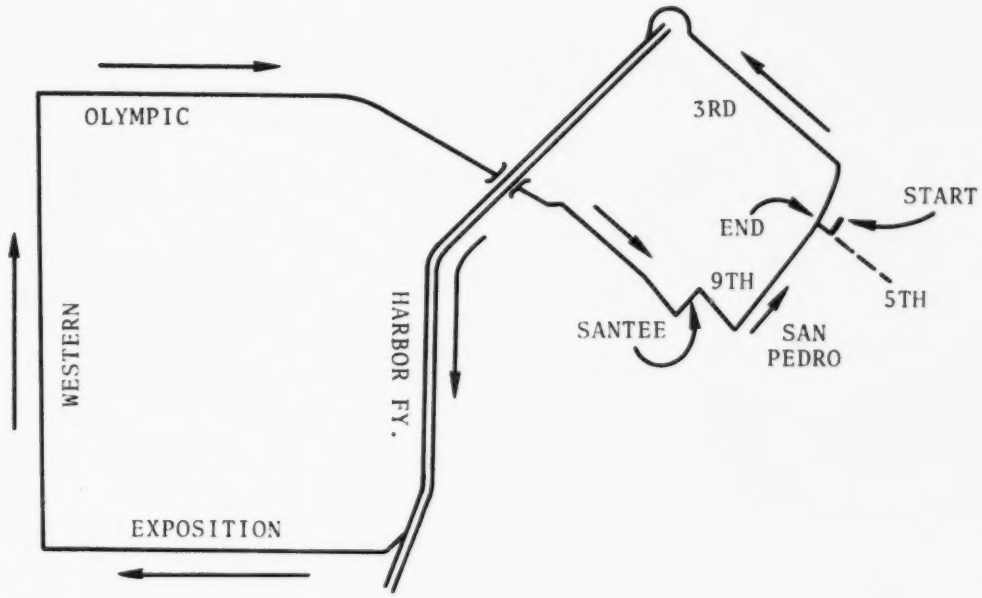
TABLE 6 HORSEPOWER SETTINGS FOR EPA EMISSIONS TEST

Loaded Vehicle Weight, Pounds	Equivalent Interia Weight, Pounds	Road Load Power @ 50 mph, Horsepower
Up to 1,125	1,000	5.9
1,126 to 1,375	1,000	6.5
1,376 to 1,625	1,500	7.1
1,626 to 1,875	1,750	7.7
1,876 to 2,125	2,000	8.3
2,126 to 2,375	2,250	8.8
2,376 to 2,625	2,500	9.4
2,626 to 2,875	2,750	9.9
2,876 to 3,250	3,000	10.3
3,251 to 3,750	3,500	11.2
3,751 to 4,250	4,000	12.0
4,251 to 4,750	4,500	12.7
4,751 to 5,250	5,000	13.4
5,251 to 5,750	5,500	13.9
5,751 to above	5,500	14.4

Source: Federal Register, Vol. 37, No. 221, Nov. 15, 1972.

(2) adjustment of the dynamometer to the appropriate test condition for the particular test vehicle, and (3) execution of the specified driving schedule during which exhaust emissions are collected. These procedural steps apply to both EPA driving schedules, the EPA urban cycle and the highway driving cycle.

The EPA Urban Dynamometer Driving Schedule is a representation of a road route in Los Angeles which is referred to as route LA-4.[2,8] This is a recognized, typical urban road route which was developed as the result of years of extensive work by California[2,8] personnel (see Figure 11).



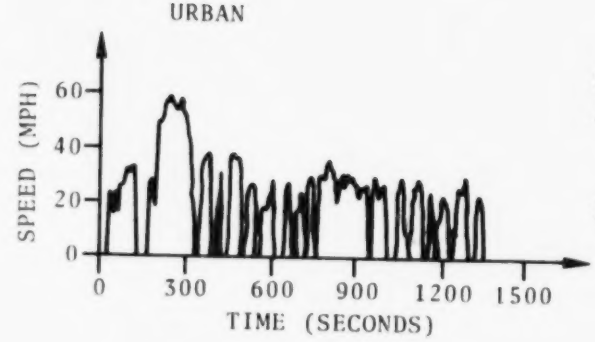
1. Start behind County Air Pollution Laboratory.
2. Right on Fifth.
3. Right on San Pedro.
4. Left on Third St.
5. Up ramp to Harbor Fy. South.
6. Exit Harbor Fy. at Exposition.
7. Follow Exposition to Western.
8. Right on Western.
9. Right on Olympic.
10. Left on Santee.
11. Right on Ninth.
12. Left on San Pedro.
13. End just beyond intersection San Pedro and Fifth Street.

Source: Vehicle Operations Survey, Scott Research Laboratories, Inc., Volumes I and II.

Figure 11 Description of LA-4 Road Route

The developers of this road route had as their ultimate goal the development of a short repetitive dynamometer cycle which represented the LA-4 road route and thus, Los Angeles urban driving.[8] They fashioned a driving schedule similar in concept to the 7-mode cycle which was used during the early years of emission certification.[9] The new cycle contained 18 modes and yet only showed fair agreement with the road and it seemed that further revisions might be required. An outgrowth of this project was the development, by EPA personnel, of the concept of recording the routes most significant parameters, route speed and time and using those parameters for the dynamometer vehicle exercise. (A further outgrowth of this study was the successful development of a rural or highway driving schedule.[25,26,18]) As can be seen from Figure 12, all of the minor speed changes which actually occur in real life driving are retained. The urban fuel economy test is a two stage test. The first stage consists of a simulated 7.5 mile urban drive at an average speed of 19.5 mph in a speed range of zero (representing stops) to 56.7 mph. The test starts with the vehicle at ambient conditions (cold start) and the vehicle warms up as the test proceeds. Eighteen stops are incorporated in the test (a frequency of 2.4 stops per mile) and about 18% of the test time in this phase is devoted to idling. This sequence lasts about 23 minutes. Then the vehicle is stopped for 10 minutes. Then the first 505 seconds of the schedule are run again from a hot start. Test data are then combined to represent the empirically measured mixture of hot to cold start driving reported in studies of actual driving patterns. To complete the data set, the warm vehicle is driven over the highway driving schedule which is a 758 second simulated 10.25 mile drive. Average test speed is 48.6 mph with speeds ranging from zero (at the start and finish) to about 60 mph. Since these driving schedules are intended to represent real life, they should be compared to those real life conditions which affect fuel economy (see Section 3.).

Unlike SAE recommendations, EPA procedures do not require a track determination of a test vehicle's road-load characteristics. During the derivation of the Federal Test Procedure in 1970, road-data submitted to EPA by various automobile manufacturers for a



	AVG. SPEED (MPH)	SCHEDULE DISTANCE (MILE)	STOPS PER MILE	SPEED RANGE (MPH)
URBAN	19.5	7.50	2.3	0-56.7
HIGHWAY	48.6	10.25	0.1	0-59.9

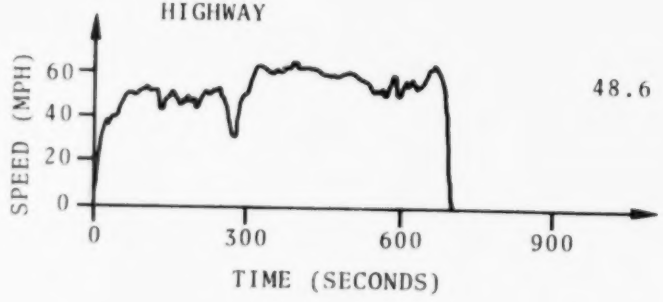


Figure 12 EPA Drive Schedules

range of vehicle sizes were used to derive "typical" road-load settings for each vehicle inertia class used in emission testing.[27] These standard road-load settings have recently been adopted for use in fuel economy tests. It should be added, however, that a manufacturer retains the option of submitting road-load data to EPA which would substantiate use of a non-standard dynamometer load setting on any test vehicle. Consequently, a vehicle which exhibits extremely good aerodynamic or frictional properties on the road can be accurately tested through EPA procedures by adjusting the dynamometer load setting to one more representative of that vehicle's road operations. The EPA procedures, however, do not penalize a vehicle which would have poorer road load characteristics than those given by the standard formula.

The second step in EPA's procedure, the dynamometer adjustment, is also much simpler and less accurate than the comparable SAE practice. The dynamometer speed meter is periodically calibrated with a strobotac or fifth wheel to verify accuracy and linearity. Prior to each test, inertia is adjusted to increments of 250 pounds for vehicles weighing less than 3250 pounds and in 500 pound increments for heavier vehicles. Then, the standardized EPA road-load is set by operating of vehicle on the dynamometer at 50 mph and adjusting power absorption at that speed to the pre-calibrated road-load set point. This calibration is performed only at 50 mph, hence, there is no specification for road-load at other speeds. EPA also does not specify dynamometer type, in terms of the number (single or dual) or size of rolls to be used.

Upon verification of the speed, inertia, and road-load accuracies, the dynamometer is properly calibrated for vehicle testing. The vehicle is driven over the specified urban or highway schedule, and exhaust emission collection is conducted. Vehicle miles per gallon are then calculated directly from the exhaust levels of carbon dioxide, carbon monoxide, and hydrocarbons. The test is considered valid if (a) deviations from the driving schedule are not greater than 2 mph for more than one second, (b) ambient temperature has remained between 68 and 86°F, and (c) all test equipment has performed within specifications. Unlike the SAE procedure, EPA does not specify final corrections to the observed fuel economy.

5.1.3 Comparison of SAE and EPA Procedures

In considering the applicability of either the EPA or proposed SAE dynamometer procedures to a fuel economy regulatory program, one must relate the practicality of that procedure to its effect on the accuracy and repeatability of the test. Table 7 summarizes the differences between the EPA and SAE procedures which are important to such a consideration.

The first three categories compared in Table 7 relate to the dynamometer's ability to accurately simulate road operation. In studying the first item listed, road-load determination, one quickly realizes the philosophical contrast between the SAE and EPA procedures. SAE attempts to simulate road-loading very accurately over the entire speed range by implementing time-consuming procedures which might prove impractical in a regulatory program. On the other hand, EPA approximates 50 mph road-load by using a more practical tabulated setting. Errors introduced by the more practical EPA method vary from vehicle-to-vehicle depending upon the aerodynamic and rolling characteristics of the particular vehicle in question.[28]

In an assessment of various road-load determination techniques, it should be realized that errors in that determination may or may not significantly affect vehicle fuel economy test results depending upon the selection of driving schedule. Data in Table 8 illustrate this point very well. As this table shows, the fuel economy of vehicles tested over the EPA urban driving cycle is quite insensitive to errors in road-load setting. On the other hand, changes in load have an appreciable effect on vehicle fuel economy over the EPA highway schedule. It should be noted that the 3-10% load errors cited in Table 8 are comparable to the differences in horsepower between inertia classes (See Table 6). Thus, the indicated change in highway fuel economy is a result of a substantial road-load error.

Because highway-cycle fuel economy measurements are much more dependent on road-load than urban tests, greater accuracy is necessary in load determinations. The proposed SAE procedures

TABLE 7. DYNAMOMETER FUEL ECONOMY MEASUREMENT PROCEDURES-COMPARISON OF EPA AND PROPOSED SAE PROCEDURES

Procedure	EPA Specification	SAE Proposed Procedure
1. Road-Load Determination	Road-load is tabulated for the various classes used in emission testing. A manufacturer may request a different road-load setting if he supplies data which substantiate the need.	Minimum of six vehicle coast-downs on the road for each vehicle to be tested. Coast-down times are determined for 10 mph increments between 65 mph and 15 mph and then corrected for ambient temperature humidity, and barometric pressure.
2. Dynamometer Specifications		
a) rolls	No specification	A large, single-roll is recommended
b) inertia accuracy	Vehicle weight less than 3125 lbs - ±125 lbs. Heavier vehicles - ±250 lbs. Maximum error - 7.7% @ 3250 lbs.	Simulation within ±5% of any vehicle weight.
c) power absorber capabilities	Power absorption vs. speed not specified.	Must simulate vehicle coast-down within ±2% over the entire speed range.
3. Dynamometer Calibration	Dynamometer coast-downs are run over a range of power absorber settings. Absorbed hp at 50 mph is calculated for all inertia weights and power settings. A pre-determined hp is thus set for each vehicle inertia class.	Vehicle coast-downs are run on each test vehicle until the corrected coast-down times determined from road data are duplicated on the dynamometer.
4. Vehicle Test Procedures		
a) ambient conditions	68-86°F; No pressure or humidity specs.	60 ±5°F; Maximum 50% relative humidity.
b) driving cycles	LA-4 Urban; EPA Highway Driving Cycle.	No cycles specified.
c) vehicle cooling	Constant speed fan. Maximum 5300 cfm air flow.	Variables speed fan which follows cycle speed within ±10%.
d) tire pressure	As requested by manufacturer; 45 psig maximum.	Maximum pressure recommended by tire manufacturers.
e) fuel measurement technique	Carbon balance.	Volumetric or gravimetric methods accurate within ±1/4%.
5. Fuel Economy Calculations		
a) basic calculation	Calculated directly from carbon balance.	Read from measuring instrumentation; resolution of 0.01 pound or 0.001 gallon.
b) corrections	None	Observed mpg is corrected for ambient temperature, pressure, humidity. Also corrected for inertia discrepancies.
c) validity	Same requirement as emissions test: (a) ambient temperature, (b) driving schedule, and (c) equipment performance must meet specifications.	A test which is in error of more than ±1% in cycle distance or ±1% in test time is considered invalid.

TABLE 8 EFFECT OF ROAD-LOAD ERROR ON FUEL ECONOMY

Vehicle	Driving Cycle	Road-Load Error	Average MPG Change
Capri	EPA Urban	-37.9%	+1.0%
Montego	EPA Urban	+27.1%	-1.6%
Thunderbird	EPA Urban	+21.5%	0.0%
Impala	EPA Highway	-10.0%	+3.0%
		- 5.0%	+3.0%
		+ 5.0%	+1.2%
		+10.0%	-4.7%
Oldsmobile 98	EPA Highway	- 7.2%	+7.1%
		- 3.3%	+2.8%
		- 3.3%	+1.4%
		+ 7.2%	-1.4%

Sources: Ford Emission Cell Correlation Program, Reference Volume I, pp. IIId-3, IIIe-1.

Response of D. J. Bonvallet, General Motors Corp., to a Letter from Charles Gray, Jr., U.S. Environmental Protection Agency, Part 10, pp. 1-3.

are designed to attain that accuracy by including the effects of various aerodynamic and tire configurations. Even if the SAE procedures do prove to be advantageous, their application to a regulatory program would be difficult, if not totally impractical. A more practical alternative and one EPA plans to pursue is to improve the EPA procedure to account for vehicle aerodynamic characteristics and rolling friction variations. Such an approach is certainly feasible, and can be implemented in about one to two years.

A final issue concerning the EPA road-load setting is the fact that the dynamometer power-absorber is set at only one speed, 50 mph, as opposed to SAE's multi-point load setting. As Table 8 shows, errors in road-load setting have a very minor effect on fuel economy during an urban driving schedule, thus the single-point setting should not affect fuel economy determinations over

such a cycle. It would also not affect testing over a steady-speed 50 mph cycle. Since speeds during EPA's highway cycle fluctuate around that speed, the effect of road-load errors at other speeds, if they exist, may be small. However, no data are available which exactly quantify this effect.

Other dynamometer factors compared in Table 7 relate to the physical capabilities of the dynamometer. The major contrast between the procedures is the fact that SAE specifies a single-roll dynamometer while EPA makes no specification. The choice of rolls may affect tire-roll interactions which could, in turn, affect vehicle loading. Consequently, it has been stated that a larger, single-roll dynamometer would most accurately simulate tire-road interactions, and would thus be preferable for conducting accurate fuel economy measurements. Considerable disagreement exists regarding the improvement to be expected from the single-roll unit, especially since dual-roll dynamometers have previously been used to produce medium accuracy results.[29] Because this issue is unresolved and considering the information available, dual-roll dynamometers seem satisfactory at this time. However, further investigation into this issue is certainly desirable.

Another issue which pertains to both the EPA and SAE specifications, is the effect of inertial inaccuracies on test results. Each procedure allows errors of at least 5 percent and it is feasible that such errors could significantly effect fuel economy. One source indicates that a 10-14 percent change in inertia can have a 5 percent effect on urban fuel economy.[26] Consequently, further investigation into this area would be advisable.

The remaining differences which exist between the EPA and SAE procedures concern the actual test conditions and fuel economy determination. In relation to the first topic, testing programs conducted independently by EPA[20] and Ford[30] have shown that test cell temperature within the limits of 68 and 86°F does not significantly affect fuel economy. The conclusions of these and other programs do not agree on the influence of barometric pressure variations on fuel economy, but in none of the studies was such an

affect deemed large.[14] Since the major advantage of a dynamometer test is the stability of ambient conditions, corrections for normal ambient variations should not be necessary in an acceptable dynamometer test cell.

In relation to the methods of measuring fuel economy, previous discussion (Section 4.2) has documented the advantages and disadvantages of various techniques. Either the carbon-balance technique, as routinely employed by EPA, or volumetric/gravimetric methods, as specified by SAE, should provide accurate and repeatable fuel economy measurements if conducted properly.

In summary, consideration of EPA and proposed SAE dynamometer-based fuel economy test procedures shows that the EPA procedures have greater applicability to a large-scale vehicle testing program. However, improvements in EPA specifications for road-load adjustment and inertia simulation will make these procedures more accurate.

5.2 TRACK BASED PROCEDURES

5.2.1 Description of the SAE Test

The SAE fuel economy task force has also prepared a hot-start track test procedure which was completed in April of 1974 and approved by the SAE Technical Board and issued as SAE J1082.

This test procedure consists of three hot start driving cycles designated urban, suburban and interstate which are run on a test track or road. Although drawing heavily from the automotive manufacturers' current practices, J1082 is, in general, more comprehensive than the manufacturers' procedures, particularly with regard to measurement conditions, instrument tolerances and fuel specifications. The stated purpose of J1082 is to provide "uniform testing procedures for measuring on-the-road fuel economy of light-duty vehicles (motor vehicles designed primarily for transportation of persons and having a capacity of 12 persons or less, or for transportation of property and rated at 6000 pounds or less)".[31] The test procedure was designed to produce

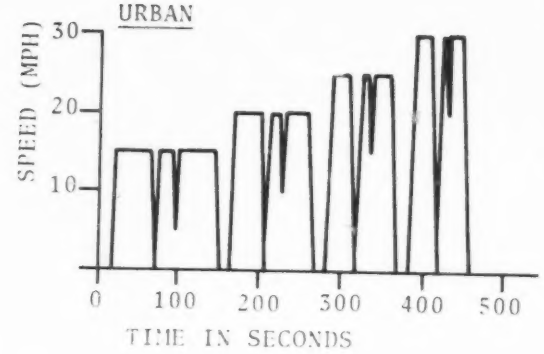
fuel economy data under conditions simulating typical urban, suburban and interstate highway driving conditions in order that reliable determinations of relative fuel economy can be made.[31]

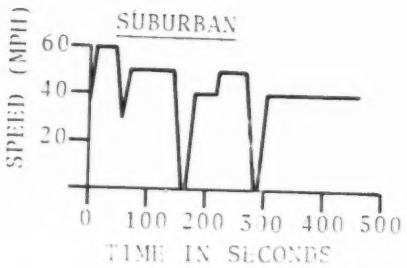
Prior to conducting the SAE fuel economy tests, the vehicle to be tested is required to have completed a 2000 mile (minimum) break-in period followed by an inspection to insure compliance with manufacturers' specifications. The vehicle is then instrumented for the measurement of fuel consumed (by weight or volumetric flow), speed (by a precision speed indication device) and acceleration. The vehicle is driven through three sets of fuel economy tests, one set for each of the three driving cycles, and the fuel consumed during the test is measured. Distance traveled is obtained either by driving over a premarked course or by using a precision distance measuring device such as a "fifth-wheel" odometer. In an attempt to minimize the effects of wind, each fuel economy test includes two runs in opposite directions on a straight track or a single run around a closed track. Two complete tests are required for each driving cycle which must repeat within 2% in fuel economy and 1% in elapsed time.

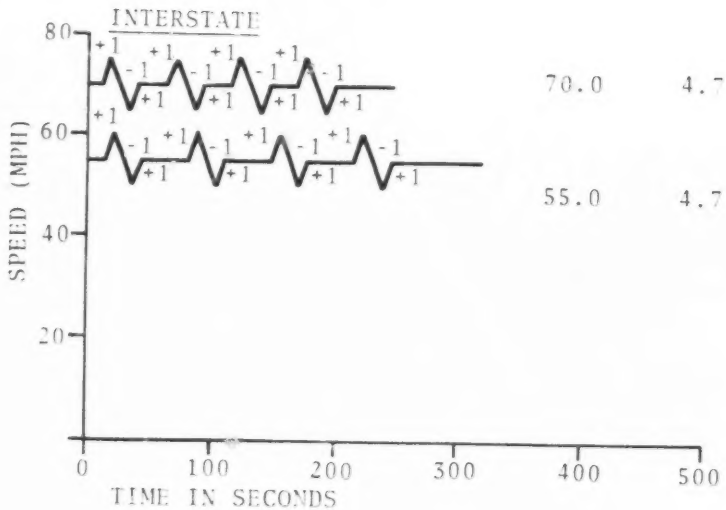
1. The Urban Driving Cycle: The urban cycle selected by the SAE (figure 13) is based on the General Motors "Central Business District" cycle with minor modifications to the acceleration rates. It consists of a series of idles, accelerations, short cruises and decelerations. The average speed of each two mile run is 15.6 mph and an average of 4 stops per mile are made. The test is run after an initial warm up drive of 20 miles at 55 mph.

2. The Suburban Cycle: The SAE suburban cycle (Figure 13) is similar to Ford Motor Company's existing suburban cycle with a maximum speed of 60 mph, 0.58 stops per mile and an average speed of 41.1 mph. The 5.2 mile test is designed to be run on either a closed track or a level straight track. As with the urban cycle, the test vehicle is fully warmed up prior to the test.

According to the SAE, this cycle provides operation representative of typical suburban driving; i.e., "high speed with relatively few stops".[32]







	AVG. SPEED (MPH)	SCHEDULE DISTANCE (MILE)	STOPS PER MILE	SPEED RANGE (MPH)
URBAN	15.6	2.0	4.0	0-30
SUBURBAN	41.2	5.2	0.4	0-60
INTERSTATE	70.0	4.7	0	65-75
	55.0	4.7	0	50-60

Figure 13 SAE Drive Schedules

3. The Interstate Cycle: This 55 mph average speed cycle was adapted from the Chrysler 70 mph interstate cycle which is 4.7 miles in length. The SAE has specified two average speeds for this test, one at 70 mph and one at 55 mph but due to current federal speed regulations, the 55 mph is the only one being used at this time.

These driving cycles should also be compared to the actual driving conditions which affect fuel economy as described in Section 3.

5.2.2 Discussion of the SAE Test

Although the SAE J1082 certainly is the most comprehensive test procedure available today for the measurement of vehicle fuel economy on the track, it has several shortcomings, some of which are specific to J1082 and some of which are applicable to track tests in general. The following discussion of the SAE procedure is not intended to be exhaustive but rather to highlight several of the critical areas.

1. Test Conditions. Section 3., Subsections 3.2 and 3.3 describe the relationship between fuel economy and ambient and road conditions. Track test results are subject to all of the variations described in Subsections 3.2 and 3.3. In order to reduce test variability, the SAE has defined minimum weather standards beyond which testing will not be allowed. Ambient temperature to be within 30 and 90°F; wind to be 15 mph or less with gusts of 20 mph or less; road to be dry, clean, smooth with grade of .5% or less. To further reduce test variability SAE uses correction factors (one for each cycle) to correct fuel economy results to standard conditions (ambient temperature 60°F, fuel temperature 60°F, barometric pressure 29.00 in Hg). It should be noted that the correction factors were derived empirically from accumulated data from the manufacturers and may not be adequately verified.

The requirement for running tests in two opposite directions does not eliminate the effects of wind since directional variation or gusts during the run will affect the measured fuel economy. Since aerodynamic drag is a non-linear function of

vehicle speed, the higher speed runs will be more sensitive to wind induced errors.

From a practical standpoint, all track tests are hampered by the requirement for dry, level (less than .5% grade) roads, and that they can only be run at certain times of the year and they are extremely subject to wind effects.

2. Drive Cycle: Although there is some evidence supporting the SAE urban and interstate cycles in generally simulating typical driving patterns,[33] the evidence for the suburban cycle is weak. This is partially due to a lack of consistency in the definition of this "intermediate" cycle. Depending upon the source, average speeds for "suburban" driving range from 24-42 mph, the stops per mile can vary over a range of 0.4 to 1.6, the maximum speed can be anything from 40 mph to 60 mph. Due to these uncertainties, it is possible that fuel economy values derived from this protion of the SAE Test may not be representative of actual consumer driving.

A second question, which has not yet been resolved, concerns the SAE technique of combining segments of constant accelerations, decelerations and cruises in a cycle designed to simulate actual driving. Such constant rate modes do not reproduce all the minor fluctuations of real vehicle operation; the necessity of including these fluctuations is still a controversial question. Such fluctuations are certainly inescapable in real driving, however, the magnitude of their effect may be less than the test variability.

A specific deficiency of the SAE J1082 procedure is the lack of a requirement for a permanent record of the exact driving schedule (speed-time profile) followed during the test. This is easily remedied by the addition of a strip-chart recorder to the instrumentation requirements, an addition strongly recommended for the purpose of verifying the driver's success in following the desired schedule.

3. Test Vehicles: In order to eliminate the possibility of systematic errors in the measured fuel economy due to variations

in vehicle preparation, installation (or removal) of optional equipment, tire selection, etc., it is absolutely necessary to have a firm specification for the test vehicle. SAE J1082 attempts this by specifying that "the test vehicle will normally be representative of a production built vehicle - any exceptions must be properly noted".[34] SAE J1082 provides a standard form for recording vehicle initial conditions, equipment and exceptions which is generally adequate in meeting this requirement. Areas of possible improvement include (a) definition of a standard test vehicle within each class, (b) improved tire specifications including rolling resistance and condition, (c) emission test data to verify compliance and (d) information concerning drivereability of the vehicle as tested.

4. Test Fuel: SAE J1082 does not specify a standard test fuel such as Indolene Clear but rather relies upon measurement of temperature and specific gravity and the application of standard correction factors. Since service station "pump fuels" can vary widely in octane rating and heating value, the test fuel specification should be improved.

5. Cold Start: The EPA's urban test (FTP) specifies a start at 68°F, the SAE currently specifies a hot engine start. It is well recognized that the reduced fuel economy experienced during cold starts must be included either during the test or as a post-test correction factor in order to insure truly representative fuel economy values. The SAE is currently considering the addition of a cold start to the J1082 procedures, however, there is concern over test variability and the possible requirement for vehicle specific correction factors.[35] It is expected that studies currently being conducted by the Department of Transportation will resolve these questions within the next 12 months.

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15. Supplementary Notes

16. Abstract

This Fuel Economy and Test Procedures Panel Report is No. 6 of a group of seven (7) prepared by special panels of the Task Force established under the joint chairmanship of DOT and EPA to conduct a study of the practicability of a fuel economy improvement standard of 20% for new motor vehicles produced in the 1980 time frame.

This report presents the test procedures recommended for insuring compliance with fuel economy regulations. Discussions included are: (a) driving variables pertinent to the establishment of a meaningful, reproducible test methodology; (b) test and measurement methods which are applicable to fuel economy certification tests; (c) current test procedures in use by industry and the federal government, and (d) recommendations for a standardized Federal Test Procedure.

The recommendation is that federally conducted fuel economy tests for labeling and/or certification be performed on a chassis dynamometer using two driving schedules - city and highway.

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